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VOLUME VI

Implications of Environmental Regulations for Energy Production and Consumption

The
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ANALYTICAL STUDIES FOR THE U.S.
ENVIRONMENTAL PROTECTION AGENCY

VOLUME VI

Implications of Environmental Regulations for Energy Production and Consumption

A Report to the
U.S. Environmental Protection Agency
from the
Committee on Energy and the Environment

Commission on Natural Resources
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1977

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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LIST OF WORKING PAPERS

These working papers represent a selection of the data on which the Committee drew when preparing its report. The views expressed in them are those of the individual authors and, unlike the main body of the report, do not necessarily reflect the consensus of the Committee. The papers are listed here as a reference for the reader. They are not bound with this volume but will be available for a limited time, in typescript format, from the Commission on Natural Resources of the National Academy of Sciences. Eventually, they will reside with the archivist of the National Academy of Sciences.

WORKING PAPER I
Automotive Air Pollution: Its Sources, Interactions, and Control
Joseph Feinstein of Varian Associates

WORKING PAPER II
The Effect of Thermal Pollution Abatement Legislation on Energy Availability
Frank L. Parker, George J. Hyfantis, Jr., and
Gregory W. Pulliam of Vanderbilt University

WORKING PAPER III
Intermittent versus Constant SO_2 Controls for Retrofit of Existing Coal-Fired Power Plants
W. Robert Menchen, Matthew S. Mendis,
H. Lee Schultz, George D. Thurston of Hittman Associates, Inc.

WORKING PAPER IV
As Low as Practicable Radioactive Emissions, Uranium Fuel Cycle
John P. Witherspoon of Environmental Sciences Division,
Oak Ridge National Laboratory

WORKING PAPER V
Coal
James Sawyer of Resources for the Future, Inc.,
and Liane Russell, Oak Ridge National Laboratory

WORKING PAPER VI
Availability of Energy Resources on Public Lands
Brent Bohlen of Harvard Law School

WORKING PAPER VII
Issues in the Prevention of Significant Deterioration of Presently Clean Air
Richard E. Ayres, Diane L. Donley, Cullen L. Phillips
of Natural Resources Defense Council, Inc.;
Barbara A. Bankoff of Government Research Corporation

Foreword

This report is one of a series prepared by the National Research Council for the U.S. Environmental Protection Agency.

In June 1973 the Subcommittee on Agriculture, Environmental, and Consumer Protection of the Appropriations Committee of the U.S. House of Representatives held extensive hearings on the activities of EPA, and the ensuing appropriations bill for fiscal year 1974 directed the Agency to contract with the National Academy of Sciences for a series of analytical advisory studies (87 Stat. 482, PL 93-135). EPA and the Academy agreed upon a program that would respond to the Congressional intent by exploring two major areas: the process of acquisition and use of scientific and technical information in environmental regulatory decision making; and the analysis of selected current environmental problems. The Academy directed the National Research Council to formulate an approach to the analytical studies, and the National Research Council in turn designated the Commission on Natural Resources as the unit responsible for supervising the program.

The other studies in the series, and a diagram of the structure of the program are presented on the following pages. Each of the component studies has issued a report on its findings. Volume I of the series, *Perspectives on Technical Information for Environmental Protection*, is the report of the Steering Committee for Analytical Studies and the Commission on Natural Resources. It describes in detail the origins of the program and summarizes and comments on the more detailed findings and judgments in the other reports.

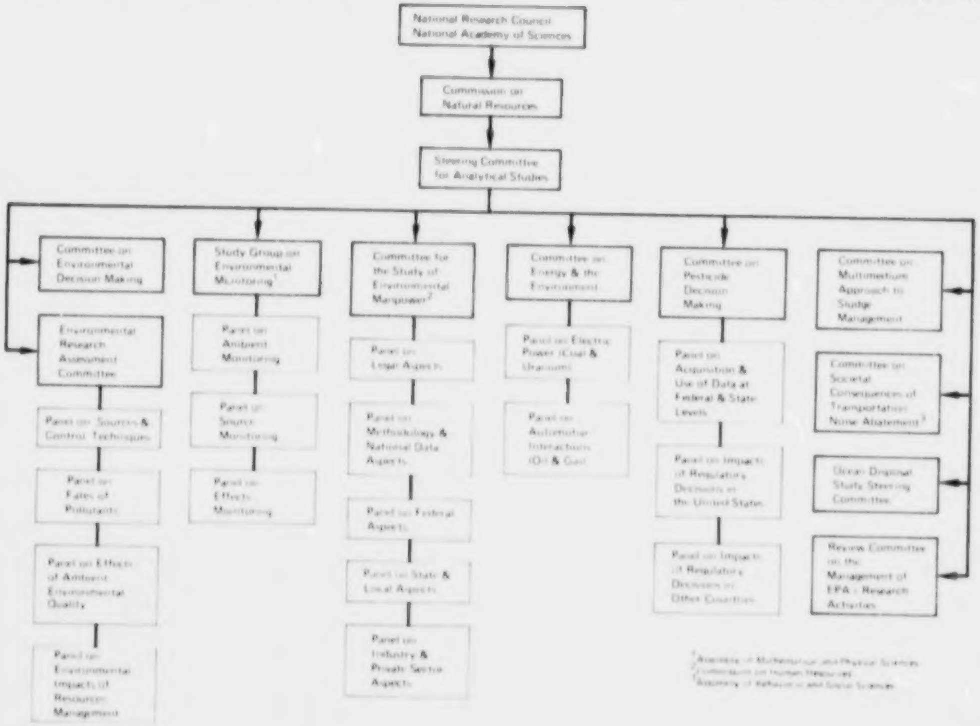
Components of the NRC Program of Analytical Studies for the U.S. Environmental Protection Agency

Project	Project Chairman	Sponsoring Unit of the NRC
Steering Committee for Analytical Studies (SCAS)	R. M. Solow	Commission on Natural Resources
Environmental Decision Making (CEDM)	J. P. Ruina	Environmental Studies Board, Committee on Public Engineering Policy
Environmental Research Assessment (ERAC)	J. M. Neuhold	Environmental Studies Board
Environmental Monitoring (SGEM)	J. W. Pratt	Committee on National Statistics, Environmental Studies Board, Numerical Data Advisory Board
Environmental Manpower (CSEM)	E. F. Gloyna	Commission on Human Resources
Energy and the Environment (CEE)	S. I. Auerbach	Board on Energy Studies
Pesticide Decision Making	W. G. Eden	Board on Agriculture and Renewable Resources, Environmental Studies Board [a]
Multimedium Approach to Municipal Sludge Management	H. O. Banks	Environmental Studies Board
Societal Consequences of Transportation Noise Abatement	W. J. Baumol	Assembly of Behavioral and Social Sciences [b]
Disposal in the Marine Environment	D. S. Gorsline	Ocean Affairs Board
Review of Management of EPA's Research Activities	R. W. Berliner	Commission on Natural Resources

[a] In cooperation with the Building Research Advisory Board.

[b] In cooperation with the Building Research Advisory Board and the Transportation Research Board.

Structure of the NRC Program of Analytical Studies for the U.S. Environmental Protection Agency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Panel on Legal Aspects
Panel on Methodology & National Data Aspects
Panel on Federal Aspects
Panel on State & Local Aspects
Panel on Industry & Private Sector Aspects
Committee on Energy & the Environment
Panel on Electric Power (Coal & Uranium)
Panel on Automotive Interactions (Oil & Gas)
Committee on Pesticide Decision Making
Panel on Acquisition & Use of Data at Federal & State Levels
Panel on Impacts of Regulatory Decisions in the United States
Panel on Impacts of Regulatory Decisions in Other Countries
Committee on Multimedium Approach to Sludge Management
Committee on Societal Consequences of Transportation Noise Abatement3
Ocean Disposal Study Steering Committee
Review Committee on the Management of EPA's Research Activities

[1] Assembly of Mathematical and Physical Sciences
[2] Commission on Human Resources
[3] Assembly of Behavioral and Social Sciences

Preface

The Committee on Energy and the Environment was established in 1974 by the Board on Energy Studies of the Commission on Natural Resources to examine the interrelationships between environmental regulations and energy and to explore improvements in the cost-effectiveness of selected federal pollution control regulations. The project was divided into two main focuses of attention, and two panels were established, one to study the implications for energy and the environment of the coal and uranium fuel cycles and electrical power production; the other to concentrate on the petroleum and gas fuel cycles and automotive end use. Nine major issues illustrative of existing and potential impacts on energy and the environment were examined in detail with the aid of consultants who prepared the working papers listed on pages viii–ix. Additional background information was obtained from workshops held with groups of specialists; from government agencies and Congressional sources; from industrial, public-interest and environmental organizations; from national laboratories, and from academic institutions. The Committee, drawing upon these various sources and upon the findings of the panels, prepared the full report that follows.

The Committee and its staff wish to acknowledge the help of the various consultants who contributed working papers and oral contributions, and the indispensable information and suggestions provided by members of the various organizations listed in the Appendix. Valuable editorial assistance was provided by Robert C. Rooney, Philippa C. Shepherd, and Estelle H. Miller of the CNR Editorial Office. Special appreciation is expressed to Morton Gorden of Development Sciences, Inc., who, as a special consultant provided ideas and suggestions during the final working sessions of the Committee; and to Albert Fry who was invaluable as EPA Liaison Officer for the project.

Appreciation is also due to Richard A. Carpenter, Executive Director of the Commission on Natural Resources, Winfred E. Berg, Executive Secretary of the Board on Energy Studies, and the staff officers of the other analytical studies for the EPA.

STANLEY I. AUERBACH, *Chairman*

Implications of
Environmental
Regulations for
Energy Production
and Consumption

Executive Summary

BACKGROUND AND OBJECTIVES

The report of the Committee on Energy and the Environment responds to Congressional concern about "the degree to which environmental regulations have contributed or will contribute to the current and the long-term energy crisis." The concern was expressed in the appropriations legislation that established the program of National Research Council analytical studies for the U.S. EPA.

The Committee studied three major questions implied in the Congressional concern: (1) To what extent is a choice forced between the availability of energy and the maintenance of environmental quality? (2) How cost-effective are current federal pollution control regulations? (3) What are the major trade-offs among health, environmental quality, energy, and economic factors in federal regulatory decision making?

ENERGY COSTS OF ENVIRONMENTAL REGULATIONS

Dollar and energy costs of environmental regulations are difficult to assess because of the complexity, constantly changing nature, and regional variation of the resource systems involved; the difficulty of reaching general conclusions about impacts that are essentially site specific; and the many uncertainties involved in predicting changes resulting from technological improvements in resource systems and emission control measures. The Committee estimated the incremental annual expenditures (see Chapter 3) made pursuant to federal pollution control legislation relating to health and the environment to be $14 to $30 billion (in 1974 dollars) for 1975, or 1 to 2 percent of the gross national product of about $1400 billion. Total economic or energy annualized costs are about twice as much as incremental costs. By 1984, the annualized incremental costs are projected to rise to $20 to $40 billion, still 1 to 2 percent of the gross national product of about $1900 billion. The corresponding numbers for the annualized incremental energy costs are 1.5 to 2.5 quads (10^{15} BTU) in 1976, or about 2 to 3 percent of the national gross energy production of about 75 quads. By 1983, the annualized incremental energy costs will rise to 2 to 3 quads, or about 2 to 3 percent of the projected gross energy production of about 100 quads. The energy costs may be expected to diminish somewhat as the adaptation of government and the private sector to environmental regulations improves, as the costs of control diminish with experience, and as the need for expensive retrofitting of industrial facilities to meet regulations disappears.

Energy supply, particularly from domestic resources, has become a critical problem for the United States. At the same time there is an imperfect market for energy because of a large difference between costs of new energy supplies and average prices of energy. In addition, not all the social costs of energy production are internalized in the current prices of energy. Since projections indicate that gaps between the marginal costs of energy and its average price will continue to grow, the energy predicament is inseparable from considerations of improved environmental quality. However, after assessing and analyzing the evidence, the Committee concluded that it is feasible and justifiable for the nation to pursue at once both the goal of sufficient energy supply and the goal of a high level of environmental quality. Federal environmental regulations require an amount of energy that is small in comparison to such other potential effects on energy supply and cost as socioeconomic factors, demographic and cultural variables, and government policies (like taxes, subsidies, and regulations affecting the extraction, use, and recycling of energy resources). A recent study showed that Sweden uses about 35 percent less energy per capita than the United States, owing mainly to government policies concerning transportation and the heating and insulation of houses. Another study estimated that it would be possible to double the efficiency of energy consumption by the end of the century through the implementation of technological substitutions that are not only feasible but also more cost-effective than increasing energy production (see Introduction to Chapter 3 for discussion of these studies).

JUSTIFICATION OF ENVIRONMENTAL REGULATIONS

The Committee discussed at length the impacts on health and the environment from various energy systems (Chapter 2). The major impacts on health are attributable to emissions of oxides of sulfur and nitrogen and to photochemical oxidants formed in the atmosphere. These pollutants result mainly from the burning of coal and, to a lesser degree, of petroleum and natural gas in power plants, and from use of the automobile. Other significant impacts on health include deaths, injuries, and sicknesses of workers in underground coal mines, of workers and members of the public during the transport of coal, and of members of the public from use of the automobile. Significant impacts on the land and water environments and on aesthetics are associated with surface coal mining and, again, with automobile operation. Thermal pollution of water resulting from power plant cooling, common to both the fossil and nuclear fuel cycles, is important because of the potentially serious effects on the aquatic environment projected for future years and the high cost of control. Aesthetic effects and land requirements for transmission of electricity from power plants are also considered significant impacts.

Certain other risks that may be significant in coming years are at present uncertain and unquantifiable. Potentially the most serious is climatic change due to the emission of carbon dioxide from the combustion of fossil fuels, particularly coal. The climatic changes may have adverse effects on agriculture, alter regional patterns of rainfall, and perhaps cause flooding of coastal areas.

The effects of nuclear accidents, sabotage, diversion of plutonium, and problems of safe management of high level radioactive waste are covered briefly in the report. However, although important to the choice of alternative systems, they were not within the charge of this Committee.

Benefits of environmental regulation accrue from avoiding or mitigating the impacts just described. Available data, however, do not provide a reliable quantitative basis for relating costs of environmental regulations to their benefits to health and the environment. Both the quality and the quantity of available information examined by the Committee were often poor; and doubts were expressed whether sufficient data would ever become available concerning the major sources of pollution, the behavior of the pollutants—including their interactions and transport and their effects on health and the environment—and the interdependence of regulatory controls. However, because of the broad and serious risks from various energy systems, the Committee was impressed with the need for implementing pollution controls simultaneously with the pursuit of further knowledge critical to the improvement of pollution control strategies.

In conclusion, the Committee found that energy costs for the nation of keeping pollution within manageable limits are small when compared to gross energy supply, or to potential savings from increased efficiencies of energy systems. However, local or regional situations may occur where an environmental regulation becomes disruptive and unjustifiable on the basis of rudimentary cost–benefit analysis. In these cases the Committee recommends flexible implementation of the regulations; for instance, waivers for old, low-load power plants in rural areas (Chapter 3, Issue 4), delays in the closed-cycle cooling requirements for power plants (Chapter 3, Issue 3), or more innovative approaches as exemplified by the "emission offset strategy" proposed by EPA, which allows, in some cases, that emissions from new sources may be offset by further emission reductions from existing facilities.

COST–EFFECTIVENESS OF ENVIRONMENTAL REGULATION

The Committee found that there are valid reasons to question the cost–effectiveness of some of our current pollution control strategies.

Continuing improvement of the effectiveness of control technology is important not only to save money and energy, but also to minimize risks of damage to health and the environment. Current environmental regulations based on impacts on health or the environment often assume a threshold level of stress below which no harmful impacts will occur. In reality, there are impacts at every level of stress, and in many cases we know very little about potential damages. The Committee would therefore prefer a regulatory process that would provide industry with incentives to improve pollution control continually, even beyond meeting existing standards, rather than a process that needs constantly to tighten regulations as effects become better understood or as economic development increases the number of pollution sources. Current regulations often provide a disincentive to develop new control technologies and to achieve better performance. Chapter 3 (Issue 7) discusses six approaches to improving the regulatory process. Two promising alternative policies appear to be emission fees and emission budget auctions. The Committee recommends their application as a source of continuous pressure for technological innovation as well as of increased cost–effectiveness of environmental regulations.

Control of pollutants is often complicated by interdependencies among them. The strategy of lowering peak engine temperatures will decrease the emission of oxides of nitrogen, but it may increase the emission of other pollutants (Chapter 3, Issue 2). Atmospheric hydrocarbons, oxides of nitrogen, and various intermediary compounds interact photochemically to produce oxidants (Chapter 3, Issue 2). Thermal pollution from power plants affects both the aquatic and air environments with interchanges between them (Chapter 2). To achieve cost-effective pollution control it is necessary to employ multipollutant and multimedium strategies. The Committee concluded that several existing environmental policies could and should be changed, with resultant savings in energy and resources and without significant loss of environmental quality. In short, it is possible to make our environmental programs more cost-effective and, while doing so, to facilitate the environmentally sound development of our energy resources.

TRADE-OFFS AMONG ENVIRONMENTAL REGULATIONS

The Committee's review of the seven issues in Chapter 3 revealed that environmental regulations involve trade-offs other than economic and energy costs versus health and environmental benefits. Since sound environmental regulations should reflect a balanced consideration of all important implications, the trade-offs discussed below should be recognized and evaluated.

Pollutant versus Pollutant

Current automobile emission regulations involve a trade-off between different pollutants. For example, increasing the working temperature of the engine results in more efficient burning of the fuel and decreases emission of certain pollutants, but increases emissions of oxides of nitrogen. Another example is the catalytic converter, which reduces hydrocarbons and carbon monoxide emissions, but may produce sulfuric acid mist (Chapter 3, Issue 2).

Risk versus Risk

"As low as practicable" radioactive emission regulations aim to decrease the exposure of employees and the public to radiation from nuclear plants. However, they may expose people to greater risks from accidents during more frequent start-ups and shut-downs of the reactor (Chapter 3, Issue 5).

Health versus the Environment

As a rule, deep coal mining creates more risks to human health, while surface mining is more harmful to the environment. Environmental regulations should strive to achieve a balance between these two kinds of risks (Chapter 3, Issue 6).

Time to Achieve Environmental Quality versus Overly Restrictive Regulations

Auto emission standards provide an example of the need for careful balancing. On the one hand, too lenient regulatory requirements may result in inaction on the part of the industry. On the other hand, insistence on rapid compliance with stringent auto emission standards for oxides of nitrogen may eliminate the diesel engine or delay the introduction of other alternative engines that promise higher efficiency and better control of the emission of other pollutants (Chapter 3, Issue 2).

ISSUES EVALUATED BY THE COMMITTEE

The Committee selected seven examples of controversial federal environmental regulation. The examples illustrated types of management decisions and alternative solutions that yield insights into the types of decision-making processes required if we are to achieve optimal efficiency among energy/environment trade-offs.

Each issue was characterized by: (a) widespread controversy regarding current regulations; (b) apparent opportunities for improvement in efficiency of energy/environment trade-offs; (c) public concern about particular environmental effects; (d) well-developed alternatives for pollution control; (e) a spectrum of regulatory acts and procedures; and (f) immediacy.

The issues were: pollution from oil and gas production in offshore waters; automobile emissions; thermal water pollution; control of sulfur dioxide emissions from electric power plants; "as low as practicable" radioactive emissions; surface coal mining and the National Environmental Policy Act; and prevention of significant deterioration of air quality.

OIL AND GAS PRODUCTION IN OFFSHORE WATERS

In this case EPA requires that best practicable technology be applied by 1977 to treat effluents from extraction of petroleum and natural gas.

Further tightening of the standards is to be applied by 1983, specifying the use of best achievable technology economically available.

An analysis of the EPA strategies for controlling the effluents shows that the current regulatory policy is motivated by technological capability rather than by proven environmental necessity. (The Agency is now considering changes to the OCS Oil and Gas Effluent Guidelines, which have been remanded to EPA by the courts.) The regulations are generally not cost-effective or even necessary. There is little evidence to justify zero-discharge technology except for particularly susceptible areas near shore-line and estuarine boundary grounds (though even this need has not been conclusively validated).

When best practicable technologies are used, the residuals from offshore oil production seem harmless and trivial in comparison with other sources of oil contamination of coastal waters, such as runoff containing waste oil from automotive and nonmarine industrial operations and tanker spills.

The offshore pollution control issue is a good example of a situation in which a better balance should be established between considerations involving the economy, energy, and the environment. In conclusion, the Committee suggests a review of the policy guidelines outlined in the Federal Water Pollution Control Act Amendments of 1972 in the case of offshore oil and gas production. A correction in policy is recommended (see Chapter 3, Issue 1).

AUTOMOBILE EMISSIONS

Light duty vehicles (cars and trucks) consume 15 percent of total energy consumed in the United States. By far the most significant beneficial impact on both pollution and energy demand would be a reduction in vehicle miles traveled, a concept that is a part of the air quality achievement plans of many regions. Obviously, the less fuel burned, the less exhaust emission from any engine.

A second obvious relationship is that engines deteriorate and that out-of-tune engines emit more pollutants and obtain lower gas mileage. Periodic maintenance (perhaps enforced by mandatory inspection) appears to be a necessary adjunct to new car certification. Otherwise the improved air quality already paid for in the control equipment will not be realized and, at the same time, energy will be wasted.

Significant improvements in fuel economy can be achieved by changes that are independent of the level of emissions: for instance, reduction of vehicle weight, use of aerodynamic configurations that reduce drag, and so on.

The Clean Air Act of 1963 and its 1970 amendments specify decreasing emissions in coming years of the levels of hydrocarbons, carbon monoxide, and oxides of nitrogen. The success of regulations in this area remains uncertain. Only about 45 percent of man-made emissions of oxides of nitrogen originate from mobile sources, while 55 percent come from power plants or industrial boilers. There are also important interdependencies between the control of oxides of nitrogen and hydrocarbons. An increase in the working temperature of the engine (to improve efficiency of fuel usage) will increase the emission of oxides of nitrogen but will usually decrease emission of hydrocarbons, and vice versa. Also, atmospheric hydrocarbons play a role in the rapid conversion of nitric oxide—the major oxide of nitrogen released during combustion—to the harmful form of nitrogen dioxide. Oxides of nitrogen, hydrocarbons, and various intermediary compounds generated in sunlight also interact photochemically to produce polluting oxidants harmful to the health of humans and animals and to vegetation and materials.

A final question remains: what additional fuel economy could be obtained if manufacturers were not required to meet the most stringent statutory standards? As technology is continually improved, it appears increasingly possible to meet the statutory HC and CO standards without sacrificing fuel economy; at present, however, achievement of an NO_x standard of 0.4 g/mile does exact a fuel penalty compared with meeting less stringent standards of 1.0 or 2.0 g/mile.

Ultimately, the choice of the final NO_x standard should be based, not on the arbitrary statutory mandate of 90 percent reduction from 1970 model vehicles, but on a rational judgment as to the benefits to air quality versus the cost of control equipment and the fuel economy penalty associated with alternative emission standards. The Committee believes that continued research on air chemistry and emissions transport and continued development of control technology will make possible such a rational decision. The cost to society, in dollars and gasoline, of a wrong decision could be considerable; thus, the Committee recommends an accelerated effort to obtain these technical data.

Because of the interdependence of oxides of nitrogen and hydrocarbons, the Committee concluded that the symmetric reduction of hydrocarbons and oxides of nitrogen mandated by Congress is not as cost–effective or environmentally sound a policy as could be derived from current knowledge. Instead, the Committee recommends a multipollutant stategy that will try to achieve a judicious balance between the control of oxides of nitrogen and of hydrocarbons by a combination of controls. Recently, the Agency has begun to develop a better understanding of these interrelationships, and to manage its programs accordingly. This approach should be continued, with even greater attention directed toward understanding the biological, chemical, and physical interactions of the various air pollutant species. The Committee further recommends that control of hydrocarbon emissions should emphasize not only automobile sources, but other major sources as well, including gasoline marketing and solvent evaporation (see Chapter 3, Issue 2).

THERMAL WATER POLLUTION FROM ELECTRIC POWER PLANTS

The Committee found that the immediate environmental benefits expected from the thermal pollution regulations are generally small, while the energy and economic penalties are significant (see Chapter 3, Issue 3 and Working Paper II). The energy penalty for closed-cycle evaporative cooling is commonly 2 to 6 percent. But without regulation, adverse impacts are to be expected in the future as more and more electric power plants line the nation's rivers, lakes, and coastal areas.

The Committee concurs with preventive strategies to eliminate a problem before it becomes serious (see Chapter 4) and would like therefore to retain much of the EPA preventive control policy. In drawing timetables for implementation, however, EPA should pay more attention to determining the impact of the proposed thermal pollution regulations. Important comparisons among environmental benefits and economic costs, energy requirements, and environmental impacts for different time periods should be undertaken.

We recommend, therefore, a flexible strategy that will combine both preventive actions and cost–effectiveness. Since, in most instances, closed-cycle cooling is not currently cost–effective either in energy or in dollars, the Committee recommends postponement of the regulations wherever the effects of thermal pollution on ambient conditions, fish, and wildlife are still negligible. However, EPA should carry out sufficient monitoring to be prepared to enact the thermal pollution regulations where and when it is necessary to prevent significant harm to the environment. Although the burden of proof in such instances should properly rest with the power plant involved, EPA should adopt a selective and sensitive pollution control policy adaptable to the variable and changing circumstances characteristic of the thermal discharge issue.

CONTROL OF SULFUR DIOXIDE EMISSIONS FROM ELECTRIC POWER PLANTS

The interpretation of the 1970 Amendments to the Clean Air Act raised a controversy over which strategy to adopt to attain the specified ambient air standards. In spite of several court decisions to the contrary, the electric utility industry argues that continuous source reduction of sulfur dioxide emissions is unnecessary and too expensive. The industry asks why it must maintain continuous control of low-level emissions while pollution levels exceed the standards for air quality only intermittently. The industry would like, in certain circumstances, to abate to a lesser degree, using tall stacks to disperse the pollutants more widely and reduce their ambient concentrations while adopting supplementary controls, such as production cutbacks and a switch to low- or medium-sulfur fuels during temporary periods of bad air quality.

Decisions on the best means of controlling sulfur dioxide emissions from power plants require a balancing of imprecisely known risks to health and the environment against substantial expenditures of energy and other economic resources. There is room for a variety of judgments as to the proper balance between these factors: while the dangers of sulfur dioxide emissions have been established in general (see Chapter 2), there is no satisfactory means of quantifying them in the particular case of sulfur oxides transported far from the source and transformed into sulfate particulates. The Committee itself included members with differing points of view.

Nonetheless, the preponderance of opinion in the Committee was that there are long-distance and time-delayed reactions of sulfur dioxide in the atmosphere. Since the sulfate problem is probably widespread rather than local (due to long-distance transport) and delayed rather than immediate, a site-and-time-specific approach such as intermittent control systems may not address the problem adequately. Furthermore, because of likely regional effects, variances for power plants in rural areas are questionable, but waivers for old, low-load plants are acceptable. The consensus of the Committee, then, is that although at present the costs of control are high, the risks to human health are sufficiently great to warrant continuous rather than intermittent controls as the basic approach to sulfur dioxide control. The difficulty of developing a basis for exceptions related to region and time lead to a judgment that a nearly uniform administration of the continuous control strategy should be used (but see the discussion in Chapter 4 of uniform versus nonuniform approaches). We chose this administratively conservative posture understanding that it is controversial (see Chapter 3, Issue 4).

The Committee suggests, however, a modification of the current regulations. While we reject the variance approach, it does seem reasonable to include a waiver of the requirement for a continuous system for old power plants that (1) operate at a low-load factor, or (2) contribute only a small proportion of the ambient sulfur dioxide concentration. The exact age and emission fractions should be set after further study. Under all circumstances, however, national ambient standards should be met. The exceptions we envisage would, stringently observed, neither alter the basic EPA approach nor incur lengthy court delays. In addition, the exceptions would prevent unnecessary burdens on electric utilities.

While there was diversity of opinion in the Committee about the desirability of particular control technologies and when they would be ready for use, the members concurred that new technology, such as fluidized bed combustion, should be encouraged, for it will meet the multiple objectives of continuous control without large energy costs.

"AS LOW AS PRACTICABLE" RADIOACTIVE EMISSIONS

The issue of achieving "as low as practicable" (ALAP) radioactive emissions from nuclear power plants presents an example of management difficulties characteristic of many environmental questions. We find that the health benefits to be expected from ALAP controls are probably small. On the other hand, costs are also relatively low. Uncertainty as to exactly how small the health risks are, or unwillingness to assign a monetary value to human life or health complicate our attempts to determine a valid meaning for the word "practicable."

Study of this issue has, however, brought to light several deficiencies in current regulations on radioactive emissions (see Chapter 3, Issue 5). First, the regulations are unnecessarily fragmented because of overlaps among regulatory agencies. Some overlap of responsibility may be unavoidable, but regulations should still be better coordinated so as to be reasonably consistent and free of confusing duplications.

Second, ALAP regulations related to emissions from the nuclear fuel cycle are not very cost-effective. The public undergoes far greater exposure from medical radiation or from exposure to radon in natural gas than from the nuclear fuel cycle, and equivalent reductions in radiation exposure from medical sources or from natural gas could be made at much lower cost. More attention should be paid to the cost-effectiveness of regulatory controls, so that the greatest benefits can be produced at the least cost.

Third, operational difficulties imposed by ALAP regulations may expose plant employees and the public to greater risks from accidents during start-up and shut-down of a reactor than would accrue from less disrupted operation at slightly higher emissions. Certainly it should be determined whether restrictive actions such as those dictated by ALAP limits could involve risks as high as or higher than the other risks it is designed to reduce.

In summary, the Committee found that the costs and energy requirements of ALAP regulations are acceptably small. It concurs for the time being with the regulations, which seek avoidance of radiation exposure from nuclear facilities, to which the public has shown great sensitivity. The Committee recommends, however, that the ALAP standards be reviewed to achieve better coordination among the responsible agencies. Trade-offs involved between cost-effectiveness and increased risks from disrupted operations to meet ALAP regulations should be studied further.

SURFACE MINING OF COAL AND THE NATIONAL ENVIRONMENTAL POLICY ACT

To meet future requirements for energy, a significant increase in production of coal must take place, and much of the additional coal will be provided by surface mining. A policy question facing the country is how much effort should be demanded from surface mine operators to assure sound environmental protection. Increased surface coal production also threatens the nation with significant impacts in the form of harm to the health of workers and the public, land disruption, and social pressures in the regions to be mined. The extent to which these impacts are reduced will depend on technical and institutional solutions.

Laws have been passed at local, state, and federal levels to improve the health and safety of coal mine workers and to protect land, water, and air from significant deterioration.

Both dollar costs and energy requirements to comply with the environmental legislation vary considerably according to the location and characteristics of the mine site. In general, energy requirements for reclaiming strip-mined land are small when compared to the recoverable energy from the mined coal. Costs of reclamation range from a few cents to several dollars per ton of coal. Only at the higher end of this cost scale are the economics of coal production significantly affected. The Committee concluded that the federal health, safety, and environmental regulations have not significantly inhibited the total national production of coal, although again, more significant impacts in some local situations are to be expected.

On balance, we find that the benefits of environmental protection provided for during surface mining outweigh the costs and delays in energy production, and that any difficulty resulting from current restrictions is a justified price to pay for the advantages of an undamaged environment. Our study of the surface coal mining issues (see Chapter 3, Issue 6, and Working Paper V) further indicated that significant delays incurred to meet regulations aimed at environmental protection are probably interim phenomena. The delays will decrease significantly with time as institutional adaptations to new legislation by both government and private sectors take place. We may expect costs of environmental protection to diminish even further relative to the overall cost of producing coal.

Coal surface mining is an issue in which the National Environmental Policy Act of 1969 can be made effective as a policy tool. NEPA provides a flexible policy suitable to the variety of impacts associated with surface mining. By early preparation and application of an environmental analysis, NEPA can be used to ease rather than hinder environmentally sound coal production. The Act would therefore become, as its authors intended, a tool for implementing " . . . a national policy which will encourage productive and enjoyable harmony between man and his environment . . . ." Substantive policy guidelines for coal development could be formed within the NEPA process to accommodate the dual objectives of environmental protection and energy production.

While judicial insistence on full compliance with the procedural dictates of NEPA has been commendable, more attention needs to be paid to the law's substantive purposes. The preparation of environmental impact statements required under Section 102C of the law was never intended to be an end in itself, but to ensure implementation of the policy mandate embodied in Section 101. Both the federal agencies responsible for the implementation of NEPA and the courts, however, have concentrated on the procedures required by the Act, neglecting the policy objectives of the procedures, with the result that NEPA's full potential has not yet been realized.

To achieve its substantive, as well as its procedural, objectives, NEPA must be regarded as a resource management tool, and must apply its mandate to broad policy and programmatic actions of the federal government.

NO SIGNIFICANT DETERIORATION OF AIR QUALITY

The nondeterioration program is aimed primarily at preserving air quality in regions that are cleaner than required by national standards without imposing formidable obstacles to economic growth and development. Regulations to achieve nondegradation will have greatest effect on electric utilities and may create problems in western states where coal and other energy resources are located close to national parks.

Numerous studies have been carried out by EPA, the Federal Energy Administration, industry, and environmental organizations to clarify the intent of Congress, and to evaluate the costs of implementing the proposed regulations and accommodating to their impact.

EPA's strategy in dealing with this problem was to establish three classes of areas: Class I, where air quality should be preserved; Class II, where moderate deterioration would accompany well-controlled growth; and Class III, where air quality could be allowed to degrade to national standards.

The 1976 House and Senate proposals for nondegradation adopted similar basic strategies, but differed from each other and from the EPA regulations in the number of class designations and whether they should be mandatory, the amounts of allowable deterioration and the stringency of the limitations, the sources and pollutants covered, and the control technologies required. (see Chapter 3, Issue 7, and Working Paper II).

The Committee concurs with the general principle of minimizing degradation of air quality because: (1) risks to health and ecosystems associated with local air pollution are high (see Chapter 2) and are reinforced by aesthetic considerations; (2) the transport phenomenon implies that degradation of the air anywhere is likely to be a threat to health and the environment in other regions; and (3) the development strategy of polluting one air shed and then moving on to the next must stop.

The Committee found EPA's three-class concept useful for protecting those areas at the extreme where we want to avoid any risk of degradation (Class I) and where the cost of compliance is at present too great (Class III). Class III areas were viewed by the Committee as areas that require a somewhat longer "grandfather clause" to allow more gradual transition to meet the more stringent requirements of Class II areas, but the hope is that they would eventually become Class II areas as well.

From the array of techniques to minimize degradation of air quality, the Committee preferred those that would be most successful in encouraging development of technology to meet more stringent levels of emission at lowest cost. Two promising policies to achieve these ends were emission fees and emission budget auctions, which can be designed to exert continuous pressure for technological innovation.

CHALLENGES TO MANAGEMENT

Efficient environmental management requires that some difficult decisions about allocation of resources be made efficiently by our environmental regulatory agencies, and that our systems of production comply with the allocations at lowest cost. These allocations are made under uncertainties about both the magnitude of the risks involved and the corrective effects of the environmental regulations. The nation's environmental programs generally intend to avoid risk of damage to human health and the environment. The Committee shares this intent. Recently, however, some environmental risks from the production and use of energy and some apparent inefficiencies in our methods for lessening those risks have become clearer. We should review now, in a systems context, how we manage our environment, and not only how we regulate pollution.

Management to minimize public and environmental exposures to risk should incorporate several essential features (see Chapter 4). The systems should encourage experiments with new solutions followed by continuous analysis of results and subsequent feedback into the system. In accomplishing this objective, we should mandate results rather than technology, because this emphasis will encourage innovation to lower the dollar and energy costs while achieving the desired benefits.

It will be particularly necessary to provide incentives to achieve levels even below current standards. The alternative is to tighten regulations continually as effects become better understood and as economic development increases the number of pollution sources. Incentives to move continuously toward better performance are also part of a strategy that focuses on prevention rather than "clean-up."

Finally, consistent with prevention as a management strategy is resource efficiency in the form of conservation and resource recovery. To the extent that primary standards and the thresholds upon which they are based are insufficient from a risk-aversion standpoint, conservation and resource recovery are exceedingly valuable bases for policy, for they may shorten the fuel cycle, ameliorate pollution, and forestall certain risks associated with energy systems.

The basic conclusion is that the inevitable trade-offs between energy and the environment are manageable, and many apparent problems can be solved or mitigated through good resource management. Mistakes in regulation can be corrected, the objectives of a rational balance can be defined in the political process, and major risks can be avoided. The more comprehensive perspective of resource management embraces, at the outset, values that are perceived to be in conflict, minimizes the conflict through more completely informed action in the present, and provides an improved chance for anticipating and preventing environmental problems in the future.

KEY RECOMMENDATIONS

- *Pollution control programs that include abatement regulations should be developed with cost–effective goals* (see Chapter 3, Issues 1, 2, and 5, and Chapter 4).

- *Efficient pollution control strategies should take a holistic approach instead of focusing on a single pollutant, single source, or single environmental medium* (see Chapter 3, Issues 1, 2, and 5).

- *To promulgate and implement environmental regulations effectively, there should be greater coordination among agencies with overlapping responsibilities* (see Chapter 3, Issues 1, 5, and 6).

- *Agency programs should actively experiment with innovative approaches to the regulatory process, such as economic incentives for improving pollution control* (see Chapter 3, Issues 4 and 7, and Chapter 4).

- *Agencies proposing and implementing pollution control regulations should undertake in-depth analysis of all trade-offs that may be involved between and within regulated sectors* (see Chapter 3, Issues 2, 5, and 6).

- *More extensive and reliable knowledge should be developed concerning major sources of pollution, the behavior of pollutants including their interactions and transport, the effects of pollutants on health and the environment, the interdependence of pollution controls, and the costs and trade-offs likely to be involved in proposed regulations* (see Chapter 2, Energy/Environment Impacts, and Chapter 3, particularly Issues 2, 4, and 7).

1 Background, Objectives, and Methodology

Over the past 10 years public concern has been growing over the health hazards, social impacts, and environmental degradation that result from our resource management systems. Although both the quality and the quantity of the information necessary for decision making on the control strategies were poor, the urgency of the task dictated that the emphasis be put on immediate control of major sources of air and water pollution. Research and monitoring activities necessary to increase the information base received only second priority. Periodic reviews of the control strategies were undertaken as new information became available. The approach resulted in significant reductions in the exposure of urban populations, particularly in the case of sulfur dioxide, particulates, and carbon monoxide.

Recently, concern has developed over the effectiveness of pollution controls in terms of money, social values, and energy consumed. The concern is often linked with an assumption that there is an inevitable conflict between desirable environmental quality, on the one hand, and excessive costs and energy consumption, on the other. The concern is also coupled with awareness that some pollution abatement goals are impossible to implement, particularly the ambient air quality standards for photochemical oxidants in the Los Angeles Basin, parts of Texas, and the northeastern corrider of the United States. There is also concern over new knowledge about synergistic effects of pollutants on humans, such as effects of simultaneous exposure to sulfur dioxide and ozone, the significance of oxidants, sulfuric acid mist, and of fine sulfate and nitrate particulates, and new evidence of long-distance transport of pollutants and their chemical precursors.

In a well-managed environmental control system there is no need for a conflict between environmental quality objectives and other social goals. It is possible to strike a proper balance between the different objectives by concentrating on cost-effective control strategies for the most important sources of residuals. For that purpose, we should examine the critical policy options available to us in respect to their costs, benefits, and effectiveness, as well as the trade-offs involved in the environmental management strategies.

OBJECTIVES

The Committee on Energy and the Environment was guided in defining the objectives of the study by the concern of Congress to investigate "the degree to which environmental regulations have contributed or will contribute to the current and the long-term energy crisis."

To investigate this question the Committee formulated the following three main policy questions:

1. Do environmental regulations make too great a demand on scarce resources of energy and the economy so that we may be forced to make a choice betwen the production of sufficient energy and the maintenance of desirable environmental quality?
2. Are our current pollution control measures cost-effective, and how can we improve them?
3. What are the major trade-offs among health, environmental quality, emission of residuals, control strategies, energy, and economic factors involved in environmental regulations?

The objective of the study was to examine the relations between energy and the environment based on the evaluation of the above three questions. The answers would help supply a basis for policy discussion.

SCOPE AND METHODOLOGY

There are many kinds of environmental regulations employing different strategies to protect environmental quality. The regulations range from broad fiscal and resource-management alternatives to direct pollution-abatement controls. Regulations may also be drafted by different authorities at federal, state, or local levels.

It is clearly impossible within the scope of the present study to evaluate all the alternatives. The Committee on Energy and the Environment therefore chose to concentrate exclusively on the energy implications of federal regulations that aim primarily to protect human health and the environment. The scope was further narrowed to the fossil fuels and nuclear fission energy systems. The Committee made a comprehensive analysis of environmental legislation and regulations to identify those laws and derived statutes that appeared to have the greatest potential impact on energy production and consumption. In the Committee's judgment, they are: the Clean Air Amendments of 1970 (42 USC 1857 et seq. 1970; PL 91-604), including the proposed amendments to prevent significant deterioration of the environment; the Federal Water Pollution Control Act (FWPCA) Amendments of 1972 (33 USC 1251 et seq. 1973; PL 92-500); the Regulation of Radioactive Materials (10 CFR Chapters 1-3, 1976); the Atomic Energy Act of 1954 as amended (42 USC 2011); the Federal Coal Mine Health and Safety Act of 1969 (30 USC 801 et seq. 1970; PL 91-173); the National Environmental Policy Act (NEPA) of 1969 (42 USC 4321 et seq. 1970; PL 91-190); and statutes governing mineral accessibility and exploitation on federal lands.

The Committee selected seven examples of controversial federal environmental regulations (see Chapter 3). The examples illustrated management decisions and alternative solutions that yield insights into the types of decision-making process that are required if we are to achieve the most efficient energy/environment trade-offs.

The major issues dealt with by the Committee were: pollution from oil and gas production in offshore waters; automobile emissions; thermal water pollution; control of sulfur dioxide emissions from electric power plants; "as low as practicable" radioactive emissions; surface coal mining and the National Environmental Policy Act; and prevention of significant deterioration of air quality.

To pursue the assessment of the energy implications of major federal environmental regulations, the Committee established two panels. One dealt with the coal and uranium fuel cycles and electric power production; the other with petroleum and natural gas fuel cycles and automotive end use. The fossil and uranium fuel cycles were selected because of the Committee's agreement to carry the study only to the year 2000. The emphasis was therefore put on coal, petroleum, natural gas, and uranium, which will be the major energy sources for the next 25 years. The end uses of electrical power production and transportation systems were selected because together they account for the major component of gross energy production and consumption. (The above selections do not imply that alternative energy systems should not be developed as rapidly as possible, or that emphasis should not be placed on energy conservation with accompanying beneficial effects for the environment. The need to achieve meaningful analyses within the time constraints simply dictated a narrowing of the focus.)

To facilitate comparisons and assure a common mode of analysis, the assessment of the seven energy/environment issues followed a common pattern. The analyses included a description of the relevant environmental legislation, a discussion of the impacts of the legislation on the production and consumption of energy, an attempt to estimate—where data were available—the annual costs of those impacts in both money and energy, a discussion of pros and cons of alternative environmental policies, and a summary statement and conclusions.

For those analysts who would like to proceed further with the discussion of energy and environment than the extent to which it is addressed in these seven issues, the Committee embedded the issues in the larger context of the major energy systems and their impacts on the environment. (See Matrices of Environmental Impacts of Various Fuel Cycles in Appendix B.)

IDENTIFICATION OF MAJOR AREAS OF ENERGY IMPACT

The Committee examined positive and negative impacts of environmental regulations on energy production and consumption. The consequences of regulation were analyzed in relation to their primary, secondary, and indirect effects on: (1) the quantities and rates of produced energy; (2) shifts in the production and consumption of energy; and (3) costs or benefits of compliance.

Effects of environmental regulations on production and consumption of energy include: changes related to the operation of the facility or equipment, employment of pollution control devices and technology, changed patterns of energy consumption, energy savings through recycling of materials, delays in production and supply translated into losses, and energy sources foregone because of environmental restrictions.

Shifts in the energy production/consumption mix are exemplified by the increased demand for clean fuels or electricity. The difference in availability of the new energy resource may be translated into increased economic and energy costs.

Economic benefits and costs refer to health, social, and environmental benefits resulting from compliance with the regulations, direct transaction and control costs, indirect costs due to the interaction between the affected sources of energy and complementary or substitute sources or products, market costs, and aesthetic benefits or costs.

The Committee recognized that many of the impacts of environmental regulations on energy are not quantifiable, and that even in the case of quantifiable effects, the assessment is complicated and often site specific. The aim of the study was, therefore, to identify the major impacts, and to develop some more-or-less quantifiable judgments and conclusions about them. The judgments were based on the Committee's views, opinions, and experience in interpreting the large number of sources of information available to it rather than on a single, agreed-upon technical methodology for balancing the energy and environmental aspects of each problem. The assessment of the impacts of pollution control on such economic measures as employment, growth, income, price indexes, or balance of payments, were not included. Also excluded were opportunity costs and comparison of the cost–effectiveness of alternative investment strategies, such as an investment in pollution control versus a similar investment in hospitals to treat the sick or subsidies to improve food diets. The feasibility and effectiveness of a strategy of managing energy demand was given only passing consideration in Chapters 2 and 4, which include some discussion of conservation of energy and resources and its consequences for the environment. The reader is referred to studies of those issues made by, among others, the Federal Energy Administration,[1] the Ford Foundation (Ford 1974), EPA (Chase Econometric Associates Inc. 1975), and the Council on Environmental Quality (CEQ 1975).

SOURCES OF DATA

The Committee obtained its information on the energy–environmental impacts of environmental regulations applied to components of the energy fuel cycles from a variety of sources. Experts in specific areas were invited to testify before the Committee or its panels, and workshops were held with groups of specialists on the specific subtopics listed. Special efforts were made to insure broad outside participation in the presentations and discussions of the issues, with diversity of viewpoints. In addition, the Committee commissioned certain papers to provide the analytical background for the seven issues addressed. (See the front matter of the report for a list of these papers, and the end matter for the names of participating specialists.) In some cases, two or more analyses representing differing viewpoints were presented by specialists from industrial and environmentally-oriented organizations. Information was obtained from government agencies, congressional sources, industrial organizations, specific industrial firms, public interest and environmental organizations, national laboratories, private policy analysis firms, academicians, and others. Selected portions of information from these sources and witnesses, and supporting data and analyses most relevant to the findings and conclusions of the Committee have been reproduced in limited quantity, and are available on request from the Commission on Natural Resources of the National Academy of Sciences. (See the front matter for a list of working papers.) The final report was based on the experience of the Committee in evaluating the different sources of information.

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[1] A complete list of the publications in FEA's *Project Independence Blueprint* series may be obtained from the U.S. Government Printing Office, Washington, D.C. The National Technical Information Service, Springfield, Virginia, also carries a partial listing of the series.

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2 Effects of Energy Systems on Health and the Environment

INTERACTIONS OF ENERGY AND THE ENVIRONMENT

The residuals from each element of a fuel cycle may have significant impacts on human health, social and ecological systems, weather, visibility, water quality, or air and land use. As society becomes more aware of the impacts, it institutes prevention and control procedures. Residuals can be controlled by removing them before, during, or after combustion; by switching to other energy systems that eliminate certain residuals or generate less harmful or smaller quantities of them; by increasing the efficiency of the combustion processes; or by reducing the level of energy consumption. Each of these actions affects the level of demand for energy or the mode of producing energy from the mix of available energy systems (see Figure 2.1).

Environmental legislation aimed at minimizing the emission of residuals has been developed in relation to specific media, specific classes of receptors, occupational health and safety, or consumer products. Analysis from the point of view of minimizing the impact of certain energy system elements on specific receptors has received little attention. (For a review of energy systems, residuals, and effects see Appendix A and the following references: U.S. Energy Research and Development Administration [U.S. ERDA] 1975; Hittman 1974, 1975; Council on Environmental Quality [CEQ] 1975.) The existing legislation makes it difficult to integrate the separate goals of environmental protection and

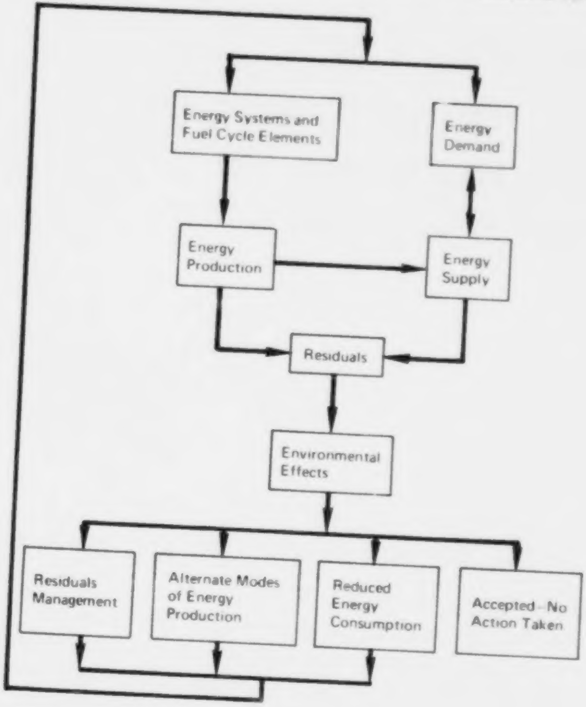

Energy Systems and Fuel Cycle Elements
Energy Demand
Energy Production
Energy Supply
Residuals
Environmental Effects
Residuals Management
Alternate Modes of Energy Production
Reduced Energy Consumption
Accepted - No Action Taken

FIGURE 2.1 Interaction of energy and the environment.

energy production, and to get the greatest possible benefit from the energy systems while holding to a minimum the amount of residuals.

Management of residuals will usually increase the direct cost of energy production for a given energy system. Depending upon the effects of price elasticity and alternative effluent control and energy production technologies, these greater costs will stimulate either the same pattern of energy consumption at higher cost, the development of alternative modes of energy production, or less consumption of energy. If the residuals are not fully managed, their effects must be accepted as a cost of society's demand for the energy.

When alternative modes of energy production are available in sufficient quantity, management of residuals may contribute to a massive switch in fuel within a relatively short time. The conversion from coal to petroleum and natural gas as a source of domestic heat is a good example of this phenomenon. Burning coal involves air pollution with particulates and combustion products, ash disposal, and formerly much manual hauling. By contrast, petroleum and natural gas are clean, easily deliverable, and readily burned. Residuals management at the consumer level was unquestionably simplified by switching from coal (or wood) to petroleum and natural gas.

In the long run, considerations of cost-effectiveness of residuals management will require assessment of alternative modes of energy production, alternative fuels and fuel sources, and conservation of energy and resources as means to achieve the same environmental benefits. Environmental legislation may directly or indirectly lead us to these considerations.

Most, if not all, environmental legislation has, however, been directed at managing residuals rather than at requiring alternative modes of energy production or reduced energy consumption. The reasons are that changes in fuel sources or methods of energy production may take decades, and reduced consumption necessitates a change in life styles or great investments to achieve energy savings, which are liable to encounter public resistance. This report therefore concentrates on the need for a sound evaluation of the costs and benefits of residuals management.

COMPLEXITY OF THE INTERACTIONS

In this report the term residual may refer to a waste material or a useful product, and will include a constituent or a precursor giving rise to a residual. The residual will be considered a pollutant at concentrations above those for which adverse effects on health or ecosystems can be demonstrated or reasonably expected from contact between the residual and a receptor. Thus, the important issue is shifted from the point at which a residual becomes a pollutant to the effects that result from exposure to it. It is difficult, but not impossible, to determine the total set of impacts from the residuals of a fuel cycle element. The steps in the process are:

1. To identify all residuals with potential health and environmental impacts resulting from a fuel cycle element. This requires identification of the chemical compounds or other environmental agents present for each residual.
2. To establish models to identify the impacts of residuals on health, ecosystems, and materials of exposed receptors. This step requires: (a) quantitative information about the amount of each constituent of the residual, including the proportion contributed to the air, water, or land;

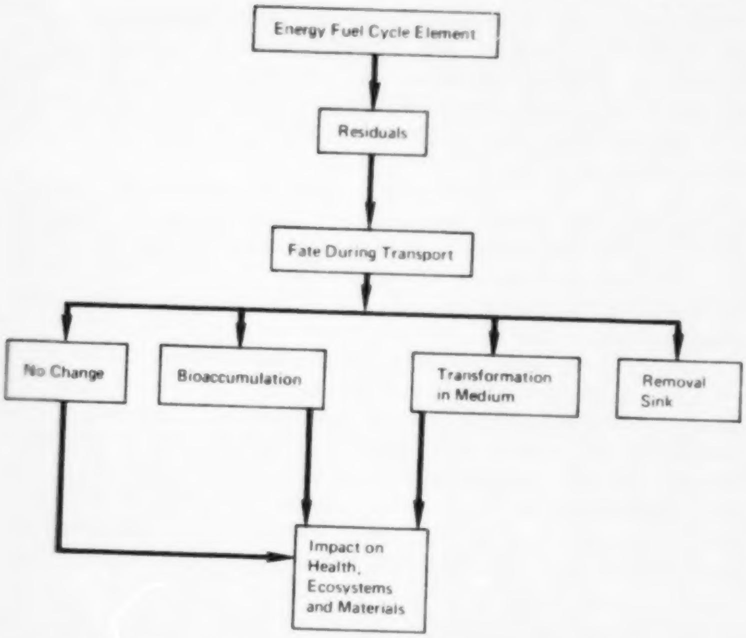

Energy Fuel Cycle Element
Residuals
Fate During Transport
No Change
Bioaccumulation
Transformation in Medium
Removal Sink
Impact on Health, Ecosystems and Materials

FIGURE 2.2 Relationship between energy residuals and their environmental impacts.

(b) knowledge of the paths by which certain chemical compounds pass through and between air, water, or land; the fate and sinks, persistence, bioaccumulation, and transformation during transport must be included so that time-related distributions of environmental concentrations at potential receptor and impact sites can be estimated (see Figure 2.2); (c) knowledge about dose-response relationships both for exposure to a single residual and to combinations of residuals; (d) estimates of the distribution and magnitude of receptor populations and material targets potentially vulnerable to exposure; (e) interrelations of distributions over time of pollutant concentrations in the environment and dose-response data for populations and materials to determine the health, ecological, and materials impact for a given moment or period of time.

A further illustration of the complexity of impact quantification for energy cycles is the difficulty that has been experienced in relating effects to various levels of different contaminants in the environment. The urban atmosphere contains a complex mixture of gaseous and particulate emissions from electric power plants, automobiles, commercial and residential heating, industrial processes, and natural sources. When we monitor or assess this complicated system, we focus attention on relatively few of the components—those that are readily identifiable as potential hazards to human health and welfare or to other ecosystems. The pollutants studied over the past two decades have been sulfur dioxide, nitrogen dioxide, total suspended particulate matter, carbon monoxide, hydrocarbons, and photochemical oxidants. Data generated from these studies were the basis for establishing the national air quality standards intended to protect public health and welfare with an adequate margin of safety.

The community atmosphere, however, is not a static mixture containing fixed concentrations of these pollutants. It is a dynamic mixture in which extremely complex chemical reactions and physical interactions continually occur. Although many new and short-lived chemical compounds are formed in this dynamic mixture, we neither monitor their occurrence nor understand their effects on health or the environment. Undoubtedly, some of the adverse health effects relate more directly to short-lived intermediate products, or to precursor substances emitted into the atmosphere, than to the primary pollutants that we monitor and control.

This complexity, however, should not discourage a commitment to regulation. The response to complexity should instead include experiment, feedback, and the flexibility needed to change tactics when the environment does not react as predicted (see Chapter 4 for further discussion of this point).

ENERGY/ENVIRONMENT IMPACTS

To make comparative assessments that will be useful for comparing and choosing among pollution control strategies, decision makers need to know the comprehensive effects on human health, ecosystems, and materials of the available energy systems, as well as the effects at each stage in the fuel cycle. Knowledge of effects, however, is inadequate and we have to be satisfied with an overview of the impacts such as is presented in the energy/environment matrix in Appendix B.

The identification of the full range of effects of energy systems on the environment presented in Appendix B was worked through to ensure that our review of the trade-offs was comprehensive. It should be noted, however, that factors additional to those included in the matrix should be considered in deciding on the selection of an energy system. A partial listing would include: (a) availability of fuel; (b) availability of resources other than fuel, such as labor and capital; (c) economic factors; (d) reliability; (e) politics; (f) public acceptance; and (g) the flexibility inherent in selecting a mix of fuel cycles as opposed to emphasis on one.

From the perspective of the energy matrix, the consequences of environmental legislation can be seen as they affect energy production and consumption as a whole. The matrix shows that no matter what energy system is used, there will be serious impacts on ecosystems and health. The effects can be reduced, but not eliminated, by imposing environmental controls on given systems at given stages in the fuel cycle. It becomes clear, moreover, that the costs and benefits of any environmental control can only be evaluated in the context of the whole fuel cycle.

CONCLUSIONS TO BE DRAWN FROM THE MATRIX

The major impacts on health and the environment illustrated in the energy/environment matrix shown in Appendix B are derived from the combustion products and particulates resulting from burning coal and, to a lesser degree, petroleum and natural gas. The impacts are largely attributable to the emissions of sulfur oxide and photochemical oxidants. Other important impacts on health include the high occupational risks associated with underground coal mining and transportation and the risk to the public from the transportation of coal. Significant impacts on the land and water environments and on aesthetics are attributed to surface coal mining. Thermal pollution of water resulting from power plant cooling is common to both the fossil and nuclear fuel cycles. It is important because of the high cost of control and the high level of potential impact. Land requirements for transmission of electricity from power plants and the magnitude of aesthetic effects are also considered major impacts.

Major impacts on public health and the environment are associated with the use of the automobile, which is an end use of the oil fuel cycle. The major risks to health are derived from accidents and from somatic damage from automobile emissions. The automobile also produces significant effects on the land and water resources and exerts social and demographic effects.

The major benefits of the various fuel cycles occur at their end uses.

In the remainder of the chapter, the effects of the different systems are discussed in the sections entitled "Effects of Fossil Fuel Energy Systems" and "Effects of the Uranium Fission Fuel Cycle." The final section, "Effects of Sulfur Oxides as Air Pollutants," illustrates the amount and complexity of information required to evaluate even a few cells in the energy/environment matrix.

EFFECTS OF FOSSIL FUEL ENERGY SYSTEMS

INTRODUCTION

The assessment of effects of the fossil fuel cycles depends upon many variables, which are often site specific, such as the variability of processes and controls employed in the different fuel cycle processes, and on the kind and quality of available data. In many cases it is possible to assess the potential adverse and beneficial impacts qualitatively, but not to quantify them. Problems of quantification are not all insurmountable, however, and many are being or will be addressed through research. It has already been estimated, for example, that the damage to health (mortality and morbidity) caused annually by particulate and sulfate pollutants costs $2080 million (Lave and Seskin 1970) and that air pollution annually causes $500 million damage to crops (Waddell 1974). However these figures should be used with caution, because they are only rough estimates that still need improvement.

In an examination of impacts, it is important to remember that residuals and impacts are not synonymous; residuals are by-products of the energy system which can have impacts, either harmful or beneficial, on the environment. Several studies have presented detailed discussions of residuals (Hittman 1974, 1975; Battelle 1973; Hamilton 1975), but detailed analyses of the effects of the residuals are not readily available.

HEALTH EFFECTS OF FOSSIL FUELS

Risk of Occupational Injury and Disease

Lave and Freeburg (1973), Sagan (1972, 1974), and the Biomedical and Environmental Assessment Group (BEAG 1974, Beller 1975) have attempted to quantify the risk of accidents and occupational diseases associated with each element of the fossil fuel cycles (coal, petroleum, and natural gas). In estimating accidents, the investigators used data collected by the Bureau of Mines, the Bureau of the Census, and the Council on Environmental Quality (U.S. Bureau of Mines 1971, 1972; CEQ 1973). The Biomedical and Environmental Assessment Group from Brookhaven National Laboratory developed estimates on the occupational hazards associated with supplying fossil fuel for one year to a 1000 MWe (megawatts electric) power plant operating at 75 percent capacity.

These estimates are presented in Table 2.1. Accident rates for coal-fired power plants diminish in proportion to the increase in the amount of coal obtained by strip mining and the extent of mechanization. Coal workers pneumoconiosis, prevalent among 10 to 30 percent of underground coal miners (Costello and Morgan 1975, Morgan et al. 1973), may decline significantly if current respirable dust standards of 2.0 mg/m^3 are achieved and if more coal is obtained from strip mines.

Of the total risk of accidental death, injury, and occupational disease attributed to each fossil fuel energy system, fuel extraction contributes the largest share, and transportation of coal and oil the second largest. Improved technologies and accident prevention programs may significantly reduce the risks; over the past 40 years, the risk of fatal and nonfatal accidents per million tons of coal mined has declined more than sixfold (NRC 1975c).

Risks to the Health of the General Population

Release of pollutants into the atmosphere from the combustion of fossil fuels is the principal hazard to the health of the general community from fossil fuel energy systems. These pollutants are known to be associated with a variety of acute and chronic diseases (see Table 2.2). Biological response ranges from irritation of the eyes and respiratory tract, to acute and chronic respiratory disease, to death. In fact, the attention of the medical community was most dramatically focused on the hazards to health from air pollution after the London fog of 1952 caused a marked increase in mortality of 4000 deaths throughout Greater London (Great Britain, Ministry of Health 1954; Wilkins 1954). In this episode, as in others, the elderly and persons with preexisting pulmonary and cardiac diseases were most susceptible.

Evidence of the adverse effects on health from fossil fuel pollutants was summarized in air quality criteria documents published by the Department of Health, Education, and Welfare and the Environmental Protection Agency (U.S. DHEW 1969, 1970a, 1970b, 1970c, 1970d; U.S. EPA 1971). Most recently, this evidence was reviewed by the World Health Organization (1972) and by the National Academy of Sciences (NRC 1973, 1975a). Table 2.3 presents a summary of the relationships between existing primary air quality standards in the United States and estimates of the presumed threshold concentration at which adverse effects on health occur (Finklea 1973). In addition to the responses listed in the table, a variety of other health effects has been associated with exposure to levels of pollutants at or somewhat higher than the stated

TABLE 2.1 Annual Frequency of Accidents and Occupational Disease Associated with Fossil Fuel Energy Systems Per 1000 MWe Power Plant

Energy System and Fuel Cycle	Accidents (No.)		Occupational Disease (Disabled Men/yr)
	Deaths	Injuries	
A. Coal			
1. Extraction[1]			
a. Underground mining	0.6 or	30.0 or	0.5-7
b. Surface[2] mining	0.3	13.0	0.5
2. Processing[3]	0.04	3.0	None apparent
3. Transport[4]	1.2*	10.0*	None apparent
4. Waste Disposal[5]	No Data	No Data	No Data
5. Combustion[6]	0.01	1.2	None apparent
Sub Total[6]	1.55-1.85	27.2-44.2	0.5-7
B. Oil			
1. Extraction[7]	0.12	12.0	None apparent
2. Transport[8]	0.05	4.5	None apparent
3. Processing[9]	0.08	5.6	None apparent
4. Transport after processing[8]	0.05	4.5	None apparent
5. Combustion[6]	0.01	1.2	None apparent
Sub Total	0.31	27.8	None apparent
C. Natural Gas			
1. Extraction[7]	0.12	12.0	None apparent
2. Processing[10]	0.01	0.05	None apparent
3. Transport[10]	0.02	1.2	None apparent
4. Combustion[6]	0.01	1.2	None apparent
Sub Total	0.16	14.45	None apparent

*Largely a risk to occupants of motor vehicles rather than to workers in the fuel industry.

[1] Assumes that only large underground mines, with one-half the national average accident rate for all underground coal mining, supply coal to power plants. Estimates of occupational disease are based only on studies of coal workers pneumoconiosis. Other diseases associated with coal mining are not included in these estimates.

[2] Fatal and nonfatal accident rates per million man-hours or per million tons of coal mined have been considerably less for surface than underground coal mining. The risk of coal workers pneumoconiosis appears to be negligible among surface workers primarily because the current respirable dust standard of 2.0 mg/m^3 is infrequently exceeded (Schlick and Fannick 1971).

[3] Death and injury rates are based on average per unit processed.

[4] Assumes rail transport over a 300-mile distance, and calculated as a proportional share of all rail freight fatalities and injuries on a ton/mile basis. The value depends directly on the length of haul, e.g., a 1300 mile haul would yield 5.2 excess deaths. About two thirds of deaths occur to occupants of automobiles which collide with trains. Barge transport is associated with 10-fold fewer injuries and deaths. Pipeline transport should lessen all risk of death and injury due to transportation.

[5] Work hazards due to air pollution from culm banks, refuse fires and acid mine drainage may occur, but no data or studies are available on this topic.

[6] Injuries due to hearing loss are an additional unquantified problem.

[7] Based on estimates by Battelle (1973). Estimates made by the Council on Environmental Quality (1973) are nearly double the Battelle figures, *i.e.*, 0.21 deaths and 21 injuries.

[8] Estimates from Battelle (1973).

[9] Estimates from Council on Environmental Quality (1973). Estimates from Battelle (1973) are 0.1 deaths and 4.2 injuries.

[10] Estimates from Council on Environmental Quality (1973).

SOURCE: Modified from BEAG (1974).

TABLE 2.2 Adverse Effects on Health of Population from Exposure to Products of Fossil Fuel Combustion

Health Effect	Remarks
I. Acute Effects	
1. Excess mortality in the general population and particularly in persons with preexisting cardiopulmonary disease	Effect is well documented during air pollution episodes. Apparent, nearly linear relationship between daily mortality and daily concentrations of sulfur oxides/particulate complex.
2. Aggravation of asthma	Reported in studies of children and adult panels of asthmatics.
3. Aggravation of preexisting chronic respiratory and cardiovascular disease	Reported in studies of patient panels, particularly of elderly persons.
4. Nonspecific irritation symptoms; eye, upper respiratory tract and nose	Most commonly observed effect of short-term exposure to peak concentrations.
II. Chronic Effects	
1. Increased risk of death from combined, respiratory, and cardiovascular causes	Risk estimates are based on comparisons of populations in areas of high and low pollution.
2. Increased prevalence of chronic bronchitis	Evidence provided in many studies, based on comparisons of disease prevalence in areas of high and low pollution. Effect of cigarette smoking is greater.
3. Increased risk of acute respiratory disease, particularly observed in studies of children	Evidence derived from many studies of illness rates in areas of high and low pollution.
4. Impaired ventilatory function in children and adults	Well established effect found in many studies from Great Britain, United States, Japan, Italy and elsewhere.
5. Miscellaneous alterations in physiological function, biochemical parameters and hematological indices	Demonstrated in experimental exposures of humans to relatively low pollutant concentrations and in a large number of experimental animal studies.

thresholds. Safety margins are generally less than 50 percent of the effects threshold (see Table 2.3).

In most cases, the degree of uncertainty concerning the presumed threshold concentration for each pollutant is larger than the safety margins contained in the primary air quality standard. For this reason, the percent safety margins stated in Table 2.3 are by no means precise. As more complete health information is obtained, the apparent margin of safety tends to diminish. Thus it is highly likely that some adverse effects on health will be identified at population exposures below existing primary standards. Indeed, some scientists question whether the assumption of a threshold concentration implied in the Clean Air Amendments (42 USC 1857 et seq. 1970; PL 91-604) is valid for all primary standard pollutants. For instance, a case could be made for potential adverse effects occurring from even slight exposure to carbon monoxide, since any exposure causes elevation in the carboxyhemoglobin saturation of the blood. In many cases, we lack convincing evidence that effects do *not* occur at population exposures below the standard. In fact, most standards are based on epidemiological evidence for increased frequency of adverse effects in quite polluted areas. The possibility has not been adequately examined that excess effects on health attributable to atmospheric pollution, albeit at relatively low concentrations, may occur in less polluted communities. We have no data on disease frequency in a nonexposed or baseline population living in a pristine environment. Even if these data were available, it would be unreasonable to attribute disease rates above baseline entirely to atmospheric pollutants, because other significant stress factors such as cigarette smoking or illness are also at work in exposed populations.

Estimates of Total Risks to Health

We lack reliable data on exposures of the total U.S. population to the pollutants listed in Table 2.3. Furthermore, we do not have adequate information on the cumulative effects on health attributable to these exposures. For these reasons, we are unable to derive firm estimates of the total risk to the health of the general community created by the fossil fuel energy systems. It is clear, nonetheless, that this burden on our health is large and widespread. A number of studies have attempted to quantify the damage to health from fossil fuel combustion products. The Brookhaven National Laboratory investigators (BEAG 1974) used linear mortality and morbidity models, which take account only of excess mortality and chronic bronchitis in an exposed population, to derive the estimates presented in Table 2.4. These estimates do not consider the other known but unquantified acute and chronic diseases or the functional impairments associated with exposure of the population to air pollutants. Neither can the estimates incorporate the unknown but suspected carcinogenic and mutagenic hazards of atmospheric substances.

The health burden attributable to carbon monoxide, photochemical oxidants, oxides of nitrogen, and trace elements has also been inade-

TABLE 2.3 Health Effects Threshold Concentrations, Air Quality Standards, and Margins of Safety for Fossil Fuel Pollutants

Safety Margins Contained in Primary Ambient Air Quality Standards

				Percent Safety Margin*	
Pollutant	Lowest Best Judgment Estimate for an Effects Threshold	Adverse Effect	Standard	Lowest Best Judgment Estimate for an Effects Threshold	For All Best Judgment Estimates
Sulfur dioxide	300 to 400 µg/m^3 (short-term)	Mortality harvest	365 µg/m^3	None	None to 37
	91 µg/m^3 (long-term)	Increased frequency of acute respiratory disease	80 µg/m^3	14	14 to 212
Suspended sulfates	8 µg/m^3 (short-term)	Increased infections in asthmatics	None	None	None
	8 µg/m^3 (long-term)		None	None	None
Total suspended particulates	70 to 250 µg/m^3 (short-term)	Aggravation of respiratory diseases	260 µg/m^3	None	None to 15
	100 µg/m^3 (long-term)	Increased prevalence of chronic bronchitis	75 µg/m^3	33	33 to 133
Nitrogen dioxide	141 µg/m^3 (long-term)	Increased severity of acute respiratory illness	100 µg/m^3	41	41 to 370
Carbon monoxide	23 mg/m^3 (8 hour)	Diminished exercise tolerance in heart patients	10 mg/m^3	130†	130 to 610†
	73 mg/m^3 (1 hour)		40 mg/m^3	82†	82 to 788†
Photochemical oxidants	200 µg/m^3 (short-term)	Increased susceptibility to infection	160 µg/m^3	25	None to 363

*Safety Margin = Effects threshold minus standard divided by standard × 100.

†Safety margins based upon carboxyhemoglobin levels would be 100% for the 8-hour standard with a range of 100 to 400% overall best judgment estimates. For the one-hour standard the lowest safety factor would be 67% with a range of 67 to 400%.

SOURCE: Finklea (1973).

TABLE 2.4 Estimated Health Effects in 1974 Associated with Production of Electric Power

Fuel	1974 10^6 KWhe	Estimated No. 1000 MWe Plants	Estimated Deaths Total	Estimated Deaths Per 1000 MWe Plant	Estimated Disabilities Total	Estimated Disabilities Per 1000 MWe Plant	Unknowns
Coal	830	126	2,000 to 20,000	16 to 160	20,000 to 40,000	160 to 320	Acute and chronic diseases Carcinogenic and genetic effects Functional impairments
Petroleum	299	45	100 to 5,000	2.2 to 110	4,000 to 9,000	89 to 200	Acute and chronic diseases Carcinogenic and genetic effects Functional impairments
Natural gas	320	48	6	0.1	600	125	Acute and chronic diseases Carcinogenic and genetic effects Functional impairments

SOURCE: Adapted from Hamilton (1975).

quately treated in these estimates. Hamilton (1975), in attempting to compensate for these unknowns, assumed that the annual mortality associated with production of 10^7 megawatt hours of electricity in 1974 may have been 4 percent of all deaths in the United States, the figure that compares with the 4.5 percent reduction in overall mortality and morbidity projected by Lave and Seskin (1970), who estimated the impact of particulates and sulfur oxides by performing regression analyses on data obtained from various studies. Lave and Seskin (1970) concluded that a 50 percent reduction in urban air pollution would eliminate 25 to 50 percent of the excess urban mortality and morbidity from bronchitis, 25 percent of lung cancers, 25 percent of other respiratory diseases, and 10 percent of all cancer. They calculated that the hypothetical 50 percent reduction in urban particulates and sulfur oxides would produce a health benefit equal to a 4.5 percent reduction in overall mortality and morbidity rates, and that the value of these health benefits in 1975 alone would have been $3.8 billion (Lave and Silverman 1976). The analysis by Lave and Seskin has been criticized for a number of reasons. There is little evidence to support the contention that, given the large contribution attributable to cigarette smoking, air pollution can explain 25 to 50 percent of excess urban mortality and morbidity from bronchitis or lung cancer. Another deficiency in the analysis stems from the lack of data on acute diseases, possible mutagenic effects, physiological disturbances, and irritative symptoms caused by exposure to air pollutants. These last effects are experienced by large segments of exposed populations, as exemplified by the prevalence of eye and chest irritation in Los Angeles. Even more difficult to assess are the biochemical and physiological changes induced by air pollution that expose people to greater risk of disease because of added external or internal stresses. Although these precursor or subclinical effects of exposure to pollutants may be relatively minor when they occur individually, the frequency of their occurrence and the potential threat from cumulative exposures may result in a major total health cost. Thus, while the analysis of Lave and Seskin appears to overestimate the health costs of air pollution for some specific diseases, it understandably underestimates some of the subtler and potentially greater adverse effects on health.

Health effects induced by the interaction of low-level air pollutants with other stresses are exceedingly difficult to identify, let alone quantify fully. As we develop more sophisticated tools for measuring the effects of exposure on human health and as our understanding of disease improves, it is likely that undesirable effects will be detected at ever lower concentrations of pollutants. This likelihood calls into question the concepts of threshold concentrations (below which no risks to health presumably exist) and margins of safety. It is becoming increasingly evident that some undesirable health consequences may be produced by very low levels of pollutants, some of them even below existing national standards. The health cost of these exposures and the marginal benefits of control cannot be adequately assessed. Generally speaking, any enhancement of air quality is likely to be beneficial to human health, and enhancement to concentrations below those achievable with current technology would be even more beneficial. Thus, society must pay some health cost for virtually all forms of energy and other benefits of technology. To date, we have not adequately addressed the question: what is the maximum sacrifice of health we are willing to accept? While science can provide some data on the magnitude of health effects at low levels of exposures, the data will necessarily be incomplete. The decision about socially acceptable risks to health must be decided in the political process.

ENVIRONMENTAL EFFECTS OF FOSSIL FUELS

Energy production from the fossil fuel cycles affects the water, air, and land environments. The effects are often interdependent and are carried through the media to affect individual organisms and plants as well as ecosystems. The effects may be short-term or long-term, local or global.

The important environmental impacts of the fossil fuel cycles are summarized in Table 2.5.

Effect on Water

The major sources of impacts on water are coal extraction and processing, oil spills, and central power plant cooling.

Coal mining affects water resources by contaminating the water, and by disturbing its flow patterns. The major contaminant is acid mine drainage which results from the exposure of the pyritic shale adjacent to the coal. Acid mine drainage, of which deep coal mining is the principal source, has destroyed tens of thousands of miles of waterways. For example, it has been estimated that over eight million tons of unneutralized sulfuric acid seeps annually from deep mines in Appalachia (Federal Water Quality Administration [FWQA] 1970). Much of the acid comes from abandoned mines. This acid drainage was shown to degrade over 10,000 miles of streams in Appalachia, kill about a million fish, and cost about $7.5 million a year in losses of recreational income alone (FWQA

TABLE 2.5 Summary of Typical Impacts Associated with Each Step of a Generalized Electricity Generation Fuel Cycle

Fuel Cycle Activity	Water	Air	Land	Biota
Extraction	Siltation, pH changes, chemical contaminations, stream channel alterations	Particulate emissions	Dedication of land areas, soil erosion, solid waste	Disruption of habitat, altered successional patterns, toxic compounds
Transport	Accidental releases	Particulate and gaseous emissions	Right-of-way	Disruption of habitat, toxic compounds
Preparation	Effluents, heat rejection	Particulate and gaseous emissions, heat rejection	Solid wastes, physical plant siting	Disruption of habitat, toxic compounds
Conversion	Thermal discharges, toxic compounds consumptive water use	Particulate and gaseous emissions thermal discharges	Solid wastes, physical plant siting	Disruption of habitat, toxic compounds
Transmission			Right-of-way maintenance	Alteration of habitat, disruption of landscape homogeniety, biocides
Disposal	Heat rejection	Gaseous emissions, heat rejection	Dedication of repository land	Releases of toxicants

SOURCE: Modified from U.S. ERDA/Brookhaven National Laboratories Workshop on Environmental Effects of Energy, held at Rockefeller University, New York, N.Y. September 4-5. BNL 20701-BEAG. Informal report.

1970). Extensive research is being done to find a solution to this problem, which at present remains largely unsolved.

Associated with the acid mine drainage and with the lime employed to neutralize it is ferric hydroxide sludge which accumulates in stream beds and on structures, smothering life and reducing the capability of gravel beds to percolate oxygen through the water.

A major portion of the extracted coal is washed with water. The process discharges "black water" which contains mostly inert dust and silt. These particulates can be easily filtered or settled to prevent pollution and siltation problems. However, the discharge water also contains dissolved chemicals, including cyanides, hydrochloric acid, and sulfuric acids which are more difficult to treat. For Appalachian conventional contour stripping of coal, where large areas of spoil are exposed on the down slope and annual rainfall is high, suspended solids may be more than half the tonnage of the mined coal (Commoner et al. 1975).

The above sources of water pollution contribute only a few percent to national water pollution problems. They are, however, very significant in some regions, such as Appalachia. Coal mining, particularly surface mining practices such as conventional contour stripping, may also affect water flow patterns, sometimes up to great distances from the mining site. Such practices may destroy vegetation over large areas with a consequent change in surface runoff patterns. In addition, exposed spoil banks from coal mining may interfere with the flow of surface water, or siltation may reduce the carrying capacity of streams and increase the possibility of flooding. Floods are also occasionally caused by accidental releases of water impounded behind waste piles or silt dams.

Total annual oil pollution of the oceans is more than 4 million metric tons (Travers and Luney 1976). The major sources of oil pollution are drainage of automotive and industrial machinery waste oil estimated at 1,753,000 tons annually, tanker operations estimated at 889,000 tons, and natural seepage of oil of about 600,000 tons (see Chapter 3, Table 3.1).

Major oil spills may contaminate local areas heavily. Such spills are caused by accidents in oil transport such as the accident of the Torrey Canyon Tanker in 1967, or in oil production, such as the oil well blowout at Santa Barbara 1969. Total annual oil pollution from vessel accidents is estimated at about 173,000 metric tons and from offshore production at about 118,000 metric tons (Travers and Luney 1976). Together, they account for about 7 percent of total annual oil pollution. Major oil spills can also have devasting short-term local effects on beaches and ocean life, covering hundreds of square miles. A recent study on the long-range effects of major oil spills caused during World War II by the sinking of oil tankers off the East Coast, on the other hand, revealed no long-range damage to the shoreland, fish, or wildlife in spite of massive spills (Campbell et al. 1977; reviewed in *The New York Times*, Wednesday, March 2, 1977).

Regardless of the type of fuel, the production of electric power releases large quantities of waste heat. A large fossil power plant will discharge about 4×10^{13} BTU per year, which affect the aquatic ecosystems in rivers, lakes, and estuaries. It has been estimated that about 40 percent of all the water used in the United States is applied to cooling electric power plants (Federal Water Pollution Control Administration [FWPCA] 1968). Although the same water may be used for cooling many times, it is clear that an upper limit of cooling water availability may be reached, as evidenced by the Rhine River in Europe. In addition to heating the water, about 0.5 to 1.5 gallons of water are evaporated for every KWh of generated electricity. Thus, a quantity of water equivalent to the flow of a major river (about 5 percent of the annual average flow of the Mississippi River) is needed for the production of electricity in the United States.

Effects on Air

Air pollution by particulate and gaseous emissions results mainly from the combustion of fossil fuels during the various steps of the fuel cycle. Particulates are also emitted during the extraction of coal, and thermal pollution can arise from central power conversion of electricity.

Table 2.6 presents estimates of the annual air emissions of the major pollutants from the various fossil fuel cycles computed for the typical 1000 MWe fossil power plant. The major pollutants are oxides of sulfur and of nitrogen, carbon dioxide, hydrocarbons, and particulates. The last category includes a great many materials of various sizes and compositions. Although the emission rate of particulates is given (and often measured) by weight, particle size is critical to assessment of biological effects. Particles in the micron size range are the most dangerous, although they may contribute insignificantly to the total particle weight. The air pollutants undergo complex photochemical reactions in the atmosphere, producing other pollutants including smogs, photochemical oxidants, and various acids. (For more detailed discussion of the air chemistry reactions see Chapter 3, Issue 2.)

Effects on Land

Land use is affected through disruptions or occupation of land during the various stages of the fuel cycle. Major land disruptions that make the land unuseable are strip mining, subsidence of rock strata overlying abandoned coal mines, and contamination of land surfaces, for instance from coal piles. The impacts on land of the coal fuel cycle needed to support a 1000 MWe power plant averaged over the 30 years' life of the plant, (load factor 75 percent),and excluding transmission of the electricity have been estimated as follows (CEQ 1973):

	Acres
Coal-deep mined	9,120
Coal-surface mined	14,010
Processing of coal	161
Transport of coal	2,213
Conversion	969

Given that about 60 percent of the coal comes from surface mining and 40 percent from deep mining, the figures show that a 1000 MWe power plant requires about 12,300 acres for mining, processing, and waste storage and about 3000 acres for structures and roads.

Other estimates (Hub et al. 1973) put the land requirements, under the same assumptions, at about 15,200 for the life of the plant.

Another source (Morris 1975), which takes into account the seam thicknesses of the underlying coal, estimated that to supply the annual requirements of a typical 1000 MWe power plant requires and disturbs about 800 acres in Appalachia, 600 in the Midwest and 100 in the northern great plains. Over a 40-year life, a plant using Appalachian coal may disturb over 30,000 acres, versus about 4000 acres for great plains coal.

TABLE 2.6 Air Emissions of Major Pollutants for the Fossil Fuel Cycles Associated with 1,000 MWe Plant

Type of Pollutant		Emissions		
		Coal	Oil	Gas
SO_2 (10^3 MT)	(10^3 MT)	24.0	21.0	0.018
NO_x (10^3 MT)	(10^3 MT)	20.0	9.0	5.8
CO_2 (10^3 MT)	(10^3 MT)	6,000	4,500	4,200
CO (10^3 MT)	(10^3 MT)	0.7	7.5	0.012
Hydrocarbons	(10^3 MT)	–	1.3	1.1
Particulates	(10^3 MT)	2.0	0.21	0.43
Radioactive				
Ra-226	(mCi)	20,000	150	–
Ra-228	(mCi)	6,000	380	–
Thermal Stack				
Discharges	(10^{10} KWh $_{\|t\|}$)	0.16	0.17	0.22
Metals	(MT)			
mercury		5.0	–	–
beryllium		0.4	–	–
arsenic		5	–	–
cadmium		0.001	–	–
lead		0.2	–	–
nickel		0.5	–	–

SOURCE: Adapted from Hub et al. (1973).

The presence of the power plant over the land and the right-of-way for transmission lines are two other major land uses. Land requirements for transmission lines vary with the number of lines and the height of towers. Right-of-way for major transmission lines varies between 100 to 400 feet (Eichholz 1976). Use of the land below the lines is restricted to pasturing or low-intensity farming. It is evident that the land demand for easements associated with power stations that may be tens of miles removed from major load centers will be very significant and greatly exceed the land area of the plant itself which would be 600 to 1000 acres. For a 1200 MWe plant 40 miles away from load centers, the required acreage will be 700 to 2800 acres.

Subsidence of the rock strata overlying abandoned coal mines is very common. Estimates (Aaronsen 1970) are that about 25 percent of the eight million acres that have been undermined have subsided; 7 percent of the total lies in urban areas. In the city, subsidence ruptures pipes, cracks buildings, and reduces land values. In rural areas, subsidence alters drainage patterns, damages crops, and also depresses land values.

BIOLOGICAL AND ECOLOGICAL EFFECTS

In considering the environmental impacts of the fossil fuel cycles, the most important concern is the affected animal and plant life.

Anything that will change environmental conditions may affect the type and character of plants and animals in a given region. Depending upon the severity of these effects, and their distribution in time and space, there will also be effects on the total ecosystems of the region.

The land affected by coal mining can be revegetated and returned to pre-mined use in from 5 to 20 years. The success of revegetation with native flora depends on climate, topography, and soil (including efforts to conserve and restore top soil). Under certain conditions, for instance in the arid West or on steep, eroding slopes in Appalachia, the land damage must be considered irreversible. (For fuller discussion see Chapter 3, Issue 6.)

THE IMPACT OF LOW LEVEL POLLUTION ON WEATHER AND CLIMATE

There is general agreement that this is a very complex and speculative subject. The knowledge to evaluate the effects is almost nonexistent. However, the potential consequences may be very severe, so that speculation at this time even with a tenuous data base is justified.

It is becoming increasingly apparent (Barrett 1975, MacCracken 1975) that chronic releases of pollutants, including heat, may have local, regional, or even global impacts on the delicate atmospheric balances of

TABLE 2.7 Potential Effects of Fossil Fuel Energy System Pollutants on Climate

Pollutant and Source	Observed Trend	Potential Atmospheric Effect	Time Scale of Importance
Carbon dioxide (CO_2) from combustion of fossil fuels	Up more than 20 percent in last 100 years	Increased global temperatures leading to melting of polar icecaps, sea level increase, perturbation of marine biology	Thorough assessment needed next 5 years—may be a problem over next 50 years
Sulfur compounds from fossil fuel	Not well-established, but concentrations may already be too high on occasion	May affect regional precipitation chemistry and acidity on regional to subcontinental scale	May presently be a problem which would be aggravated by further coal burning
Dust from combustion, slash/burn agriculture, and improper land conservation	Not well-established because of evolution of sources and particles sizes with controls	Initial response is temperature change (sign dependent on location and source type), precipitation modification. Problem is mainly on subcontinental, but possibly up to global scale	Further evaluation needed as improved data available
Heat and water releases to the atmosphere from the energy generation process (thermal pollution, cooling towers, etc.)	Increasing with energy generation	Temperature and precipitation modification on local and regional scale	Evaluation needed in regions of concentrated energy generation (e.g., energy parks, etc.)

SOURCE: Modified from MacCracken (1975).

energy, radiation, and water. Table 2.7 lists some of the pollutants associated with the fossil fuel energy systems, their potential effects, and ways in which these effects can be more precisely assessed. Essentially, all affect either radiation or precipitation, two processes fundamental to determining climate.

Three categories of pollutants from the fossil fuel cycles may affect climate. Carbon dioxide, and to a lesser extent such gases as oxides of nitrogen have the potential to modify the thermal balance of the atmosphere. Particles may affect climate through control of the atmospheric heat balance. Direct introduction of heat into the atmosphere may also eventually affect the climate by increasing temperatures and affecting the atmospheric convection.

For fuller discussion of effects of pollutants on climate see the statements of Epstein, McQuigg, and Knox before the House Committee on Science and Technology (U.S. Congress, House 1975) and Baes et al. (1976).

EFFECTS OF THE URANIUM FISSION FUEL CYCLE

INTRODUCTION

The health and environmental impacts of the nuclear fission fuel cycle are of two distinct kinds: those associated with normal operation; and those involving emergencies, such as accidents, diversion of fissionable material, or sabotage of nuclear facilities. Numerous attempts have been made to develop elaborate analyses or models for determining the probabilities and consequences of such occurrences. Some of these models are extremely comprehensive and take into account all relevant factors involving the plant, the environment, and the role of humans. The most elaborate model can be found in the Rasmussen Report (U.S. AEC 1974c), which divides reactor accidents into major categories and offers a scheme by which the probability of an accident multiplied by its average consequences provides a measure of average risk for a given category. The analysis identifies the principal contributors to major categories of accidents and the critical pathways and links that need special safeguards.

The potential for diverting fissionable material from the nuclear fuel cycle to use by terrorists or saboteurs is currently receiving national attention (Willrich and Taylor 1974). Here again, quantification of the problem is being attempted, to enable effective prevention or mitigation. For example, attempts are being made to use methodologies similar to those used for accidents to deduce the paths by which diversion or sabotage might take place, and to take precautions against them. Safeguards systems to protect plutonium fall generally under the headings of physical security and materials accountability (U.S. AEC 1974b).

Disposal of long-term radioactive wastes is another problem that still lacks suitable solutions. Difficulties arise from severe scientific and technological limitations and from inadequate social and institutional strategies for coping with the long, highly toxic life of radioactive wastes. The most promising solution currently appears to be deep underground burial of solidified wastes in selected geologic formations. (The reader is referred to the work of two other committees of the National Research Council—the Committee on Nuclear and Alternative Energy Systems, whose report is due soon, and the Committee on Radioactive Waste Management [NRC 1975b]—for more extended treatments of the problems discussed above. A comprehensive review of the various alternatives for managing high-level wastes is presented by Battelle [1976].)

HEALTH EFFECTS OF THE NUCLEAR FUEL CYCLE

Our knowledge of the biological effects of ionizing radiation exceeds our knowledge of the effects of any other chemical or physical agents. Much of this information has been reviewed in *The Effects on Populations of Exposures to Low Levels of Ionizing Radiation* (NRC 1972) and in *Ionizing Radiation: Levels and Effects* (UN 1972). In contrast to our inability to quantify the effects of fossil fuel pollutants on health, we are able to make quite sophisticated estimates of the risks to health from exposure to ionizing radiation.

Risk of Occupational Injury and Disease

Risk estimates derived by Brookhaven's Biomedical and Environmental Assessment Group (1974) are given in Table 2.8. Sagan (1972) developed similar estimates, which are presented in the footnotes to Table 2.8. As is the case with fossil fuel energy systems, the greatest risk to the health of a particular exposed individual in the nuclear fuel cycle is associated with mining. To compare the relative cost of accidents and radiation exposure of workers in different fuel elements of the nuclear industry, Sagan (1972) averaged the accident frequency for the years 1969 and 1970, and assumed a cost of $300,000 per death, $100 per day lost due to injury, and $30 per person-rem of exposure. (This estimate is Sagan's. The Committee has used an estimate of $1000 per person-rem in its calculations, which is consistent with the Code of Federal Regulations [CFR].) These data reveal a tenfold greater health cost per person in uranium mining than in other elements of this fuel cycle (see Table 2.9).

Uranium miners exposed to high dose rates from radon and its decay products were found to have excess risk of lung cancer. Lundin et al. (1971) demonstrated a 9.4-fold increase in lung cancer among 3366 uranium miners followed from 7 to 50 years after their first exposure. Average radiation tissue dose for this group was 475 rads. The absolute risk of lung cancer, derived by fitting a straight line from origin through observed dose response data, was 0.63 cases of lung cancer per million

TABLE 2.8 Risk of Occupational Injury and Disease Per Year Per 1000 MWe Nuclear Power Plant

Fuel Cycle Element	Accidents		Occupational Disease (Excess Cancers)
	Deaths	Injuries	
Extraction (underground mining)[1]	0.09	3.5	0.1
Processing[2]	0.05	0.6	0.04
Transport[3]	None	None	None apparent
Reactor[4]	0.01	1.3	0.02
Waste disposal[5]	No data	No data	No data
Total	0.26	11.9	0.14

[1] Estimates based on data from the Council on Environmental Quality (1973). The U.S. Atomic Energy Commission (1974a) estimates 0.01 induced cancers. Sagan (1972) estimates 0.1 deaths, 106 days lost due to injury, and 0.015 excess lung cancers at four working-level months per year. Comar and Sagan (1976) estimate 0.065 to 0.41 deaths from occupational accidents, 0.039 to 0.45 occupational deaths from disease, and 4 to 13 occupational injuries per year associated with the nuclear fuel cycle related to the operation of a 1000 MWe power plant. Premature deaths for the general population are estimated at 0.01 to 0.16 (Comar and Sagan 1976).

[2] Based on data from the Council on Environmental Quality (1973). Sagan (1972) estimates a total of 0 deaths, 4,900 days lost due to injury, and 0.1 excess cancers (based on about 1,300 person-rem exposure in the reprocessing industry in 1969, and 1 cancer case per 10^4 person-rem exposure) in the production of feed materials, production of special materials used in reactors, fuel element fabrication, and fuel reprocessing to service the total of about 10,000 MWe nuclear capacity of the United States as of December 1971. Therefore, Sagan's figures convert to 0 deaths, 490 days lost due to injury, and 0.01 excess cancers for the fuel manufacture, processing, and reprocessing needed to service a 1000 MWe nuclear power plant. In 1969, there were also 2 deaths and 3,200 days lost due to injury in design and manufacturing of reactors and other nuclear facilities. The latter data have not been incorporated into the estimates, because accidents related to construction have not been considered in any of the calculations on the effects of the various energy systems.

[3] BEAG (1974) states that transport of nuclear materials "involves comparatively negligible accidental injuries or routine exposures to radiation." In 1969, an estimated 4700 short tons of U_3O_8 were produced domestically and sold for electricity production (Lave and Freeburg 1973). By contrast, 2 million tons of coal per year are required to supply a single 1000 MWe coal-fired power plant (Sagan 1974).

[4] Based on data from the Council on Environmental Quality (1973). Carnow et al. (1974) estimates 0.03 accidental deaths and 3.6 accidental injuries. Sagan (1972) estimates 0 deaths, 10 days lost due to injury, and 240 person-rem exposure of utility employees (which translates to a cancer risk of 0.02 cases per year) per 1000 MWe power plant.

[5] No data are available to derive risk estimates for accident frequency and radiation exposure from commercial high-level waste disposal systems.

SOURCE: Modified from BEAG (1974).

person years per rem exposure. The risk for cigarette smokers was considerably greater than that for nonsmokers; in fact, uranium miners who were nonsmokers did not reveal an excess risk of lung cancer, although the number of miners who never smoked was too small to draw firm conclusions about this group. Lundin et al. (1971) made the estimates shown in Table 2.10 for uranium miners who are assumed to begin their exposure at age 20, work to age 50, and be monitored to age 80.

At present the occupational limit is 4 WLM per year. This implies that each miner incurs an added risk of 0.00053 cases of lung cancer per year for 30 years (Sagan 1972) or an added risk of 1 case per 1887 persons exposed per year. Thus for the 620 miners involved in underground mining of uranium in 1970, we would expect one excess case of cancer in three years. (In the United States, approximately 60,000 deaths from lung cancer occur each year, and 90 percent or more of them are attributable to cigarette smoking.)

Risks to Health of the General Population

Two categories of risks to the health of the general population from exposure to low levels of ionizing radiation must be considered: somatic and genetic. We exclude any discussion of catastrophic events, such as the failure of emergency core cooling systems, nuclear theft, and the mismanagement of wastes. These risks, though possibly the determining factor in the choice between nuclear and fossil fuel systems are simply beyond the scope of this Committee's report. (The National Research Council Committee on Nuclear and Energy Systems is preparing a series of reports on this topic.)

Somatic Risks Risk estimates for population exposure to low levels of ionizing radiation are based on linear extrapolation from effects observed in follow-up studies of the Japanese survivors of the atom bomb and British patients given radiation therapy for ankylosing spondylitis (NRC 1972). In both cases, the radiation exposure dose rates were above one rem per minute. A study by EPA (1976) estimated that the average individual exposure in the United States in the year 2000 (1000 reactors) would be 0.05 mrem/year. A risk estimate is derived by assuming (a) that risk is linear with dose, beginning at zero dose (i.e., thresholds for effects are not assumed), and (b) that dose rate has no effect on risk (i.e., a single total dose has the same risk as the same dose distributed over a large population or over a lifetime).

Sources of exposure of the general population should be compared

TABLE 2.9 Annual Cost Estimates, Accident Frequency, and Radiation Exposure of the Workforce Attributable to the U.S. Nuclear Energy System, 1969–1970

Activity	No. Persons Involved	Deaths	Days Lost Due to Injury	Person-Rem Exposure	Total $ Cost	$ Cost Per Person Per Year
Uranium mining[a]	620	1[a]	1060[a]	1540	$452,000	$730
Fuel fabrication, processing and reprocessing	6630	0	4870	1330	527,000	79
Reactor operation	1290	0	100	2400	82,000	63
Total	8540	1	6030	5270	$1,061,000	$124

[a] Figures appear to be low. Better estimates are approximately 10–20 deaths and 20,000 to 40,000 man-days lost.

SOURCE: Sagan, L. A. (1972) Human costs of nuclear power. *Science* 177:487–493. (Copyright 1972 by the American Association for the Advancement of Science.)

TABLE 2.10

Radiation Exposure (working level months per year)	Total Number Lung Cancers per 1000 Miners (to age 80)
12 WLM	68.4
4 WLM	51.2
0 WLM	35.3

SOURCE: Lundin et al. (1971).

with average exposure doses in evaluating the risk of public exposure to nuclear power plants. Exposure doses can be expressed in two ways: average rems exposure per person, and total dose accumulated over the entire population, i.e., person-rem. These doses are shown in Table 2.11, arranged by decreasing importance. The table indicates that at present the population dose from the uranium fuel cycle is about 0.01 percent of natural background, and about 0.03 percent of medical radiation. Even by the year 2000, when average personal exposure is expected to reach 0.05 mrem/year this exposure will be less than 0.05 percent of exposure from the natural background.

For the U.S. population in general, including occupational exposure, the three major sources of radiation are natural radiation from the environment, medical radiation, and technologically enhanced natural radiation (whose sources are either radiation or radionuclides found naturally in ores, consumer goods, or in wastes). On an individual basis, the largest radiation doses come from technologically enhanced natural radiation and occupational involvement. Large fluctuation from one location to another occurs in the above sources of radiation. There are however many gaps in the dose data that require follow up.

To determine the risk of radiation effects at low levels of exposure, such as those that are projected from nuclear power generation, "requires better knowledge than is now available of the mechanisms involved in the production of such effects, of their dose-response relationships, and of the susceptibility of human populations at risk" (NRC 1972). Certain effects of ionizing radiation—cataract induction, impairment of fertility, and acute injury—show a nonlinear relationship between effect and dose. There appears to be little or no risk of inducing such effects at doses or dose rates approaching natural background levels. The most important effect of radiation on human populations is the induction of cancer, and this effect according to most radiation biologists, is linearly related to dose. The relationship of radiation to mortality from causes other than cancer is still uncertain (NRC 1972).

In survivors of the atomic bomb and in patients treated with radiation

TABLE 2.11 Summary of Estimates of Annual Whole Body Dose Rates in the United States (1970)

Source of Ionizing Radiation	Average Dose per Person mrem/year	Total Dose to U.S. Population 10^6 person-rem/year
Ambient–Cosmic	41–45	9.7
–Terrestrial	60	12.3[a]
Medical	36[a]	7.4[a]
Technologically enhanced natural radiation	13[a]	2.7
Global fallout–1969	4.0	0.8
1980	4.4	1.1
1990	4.6	1.3
2000	4.9	1.6
Occupational and industrial	0.8[c] 0.003[d]	0.006[a]
Consumer products	0.003	0.006[a]
Uranium fuel cycle	0.01[b]	0.002

[a] Derived number, based on U.S. population of 205,000,000 in 1970.

[b] The number seems low.

[c] For all occupations.

[d] Based on 0.8 mrem per year for occupational workers and 3.76 radiation workers per 1000 people.

SOURCE: Derived from U.S. EPA (1976).

for ankylosing spondylitis, an increased incidence of all forms of leukemia, except the chronic lymphocytic type, was evident within two to four years after exposure. Incidence began to decline within 15 years, but the leukemia incidence still persists at rates somewhat above background 30 years after exposure (NRC 1972). The slope of the fitted linear regression corresponds to a risk of one case of leukemia/10^6 person-rem/year. Susceptibility to induction of leukemia appeared to be several times greater in persons irradiated in utero or during childhood. Other cancers found in excess in these exposed populations include cancers of the thyroid gland, lung, breast, bone, and gastrointestinal tract. Estimated risks for each of these cancers has been calculated to be in the range of one to three deaths/10^6 person-rem/year. However, dose-response data for these sites are more limited and less reliable than for leukemia.

In the Japanese survivors of the atomic bomb, excess mortality from all forms of cancer including leukemias corresponds to a cumulative total of 50 to 78 deaths per million person-rem over the period from 1950 to 1970. In radiation-treated spondylitis cases, the excess mortality corresponds to 92 to 165 cancer deaths per million person-rem during the first 27 years after irradiation. From these results, it has been estimated that continued exposure of a population to one rem per year would produce the number of cancer deaths each year equal to the cumulative totals given above, resulting from one-time exposure, provided the effect of a given incremental exposure did not persist beyond 25 years after exposure. Considering a variety of ways to estimate cancer risk, the Committee on the Biological Effects of Ionizing Radiation concluded that the risk of continuous population exposure to 0.1 rem per year, which is equivalent to the natural background level in the United States, can be crudely estimated as 15 to 20 cancer cases per million exposed people per year (NRC 1972). (An updated and revised version of this report is expected in 1978.) If this response is extrapolated to a population of one million people living in the vicinity of one or more nuclear reactors and exposed for 75 years to 0.005 rem per year, the cumulative cancer risk is calculated at 55 to 75 excess cases. (This is the limit for radiation exposure of members of the public near reactors [U.S. AEC 1971, U.S. NRC 1975].) The expected number of cancer cases in the general population, given current cancer mortality rates, is approximately 100,000 cases over a lifetime. Thus lifetime exposure at the allowable limit of radiation from a nuclear reactor would, under the linear model and assuming no dose rate effect, increase the current cancer rate by 0.010 to 0.015 percent.

The Committee on Biological Effects of Ionizing Radiation cites several cogent radiobiological reasons for doubting that the dose-incidence relationship for human cancer induction does remain constant at low doses and low dose rates (NRC 1972). These reasons include the following:

- repair of most types of radiation injury occurs at low doses and low dose rates: thus estimates based on the linear model should be regarded as upper limits of risk for low-level radiation;
- because of greater killing of cancer-susceptible cells at high doses, extrapolation to low doses may tend to underestimate the cancer risk; and
- side effects at high dose levels may enhance the carcinogenic action of radiation under certain circumstances.

There is, in short, no sufficient theory of radiation carcinogenesis from which the concept of a threshold dose may be deduced, and a threshold for carcinogenesis has not been empirically demonstrated. The estimates of cancer risk at very low dose levels (i.e., at 0.001 to 0.1 rem per year) yield such low numbers that they are virtually beyond empirical demonstration against the high spontaneous, background, or current cancer mortality rates. Thus it seems unlikely that the presence or absence of a true threshold for cancer in human populations can ever be proved; and to minimize loss of life, administrators and policy makers will continue to be forced to rely on no-threshold models.

Genetic Effects To date, no genetic effects have been demonstrated in the offspring of irradiated human populations. Therefore, estimates of risk are based primarily on experimental work with mice. The major genetic hazard from small experimental radiation doses and low dose rates probably results from the induction of gene mutations and small deficiencies in the male. A dose-rate effect is apparent on mutation induction in male mice; the mutation frequency falls off as a given total dose is delivered over a longer period of time. However, below about 1 rad per minute (rad/min) there is no further reduction in mutation frequency as dose rate is lowered. This argues against any threshold level or dose or dose rate, and it is assumed that for dose rates below 1 rad/min the mutational response in the male will be linearly related to dose. In female mice, the effects of radiation at dose rates below about 0.01 rad/min are small compared with those seen in the male. This applies to all the germ cell (oocyte) stages tested: mature, maturing, and immature arrested stages. In the arrested oocyte stage, no statistically significant increase over spontaneous mutation frequency has been detected, even after large accumulated doses.

To recapitulate, most of the genetic hazard from low radiation dose rates is seen in male, rather than female, mice; and the mutation frequencies at low radiation levels in the male are believed to be linearly related to dose. Relative to natural (about 100 mrem/year) and other man-made sources of radiation (about 50 mrem/year), the dose from nuclear power generation (about 0.01 mrem/year now, and projected to 0.05 mrem/year by the year 2000) appears to be small; possible genetic effects should thus be a lesser factor in the choice of nuclear power as an energy system.

ECOLOGICAL EFFECTS OF THE URANIUM FISSION FUEL CYCLE

Introduction

As in fossil fuel energy systems, all elements of the nuclear fission fuel cycle may have some ecological impact. More is known about the nature and extent of ecological effects that may result from emission of radionuclides and radiation than about effects of pollutants from fossil fuel cycles, but there are still many uncertainties. Significant deficiencies still exist in our understanding of sources of pollutants and emission inventory data, of the relationship between emissions and environmental concentrations over specific regions, of the transport and concentration of radionuclides along environmental pathways, and of the damage functions of pollutants affecting the environment.

Major Impacts

Uranium is mined primarily in the arid and semiarid regions of the United States by either underground or open-pit methods. The primary effect is land disturbance, with resulting impacts on terrestrial ecosystems. As yet, the amount of land disturbed is small, but could increase dramatically as lower grade ores are mined to meet the requirements of an expanding nuclear industry. Since most of the mining occurs in arid and semiarid regions, reclamation will be difficult, if not impossible. Uranium mining does not produce acid mine drainage, and the problem of radiation exposure appears to be an occupational hazard limited to the mine workers involving negligible risk to ecosystems.

Uranium ore is usually milled on or near the mine site. The principal ecological impacts of milling are the need for land for the disposal of the tailings left after ore extraction, and the radioactivity associated with the tailings. At present, more land needs to be committed permanently to this process than to any other element of the nuclear fuel cycle (with the exception of power transmission). Because of the radium and thorium found in the tailings, the land used for disposal of tailings must be restricted and off-limits to the public.

After milling, the uranium concentrate is converted to uranium-hexafluoride. The environmental impacts at this step in the fuel cycle are relatively site specific. Radioactive emissions are fairly small and have no demonstrable effect on the environment. Nitrates released to the receiving water body could cause minor eutrophication problems. Fluorides are also released to the environment; although the effects of fluorides vary according to conditions at the site.

The impacts associated with uranium enrichment are primarily, but not entirely, site specific. The enrichment plants require large amounts of land and abundant water resources; cooling towers are needed. The process uses a great deal of electricity, most of which is at present produced by fossil fuel plants; consequently, the impacts associated with fossil fuels must be considered in an evaluation of the impacts of the nuclear fuel cycle. Nitrates and phosphates are released during enrichment, but the effects of these releases are localized and can be controlled. The substantial amounts of hydrogen fluoride that are also released may affect nearby vegetation and crops.

TABLE 2.12 Nuclear Plants–Potential for Climate Modification

Pollutant and Source	Observed Trend	Potential Atmospheric Effect	Time Scale of Importance
Krypton-85 from nuclear fuel reprocessing and power plants	Building up proportionally with nuclear power generation	Modification of the atmosphere's electric field, which may cause modification of the hydrologic cycle	Thorough assessment needed; may be a problem over next 100 years with growth of nuclear power industry
Heat and water releases to the atmosphere from the energy generation process (thermal pollution, cooling towers, etc.)	Increasing with energy generation	Temperature and precipitation modification on local and regional scale	Evaluation needed in regions of concentrated energy generation (e.g., energy parks, etc.)

SOURCE: Modified from MacCracken (1975).

In fuel fabrication, the primary residuals are nitrates and ammonia effluents (which could cause eutrophication problems if not controlled) and hydrogen fluorides (which could affect nearby plants and crops if concentrations are not controlled).

The same kinds of ecological impacts as those discussed above in relation to the fossil fuel cycle are involved in the transportation of ores, nuclear fuels, spent fuels for reprocessing, and wastes. The total impact, however, is smaller because nuclear fuels are much more concentrated sources of energy than fossil fuels, so that smaller quantities both of ores and overburden and of fuels and wastes need to be handled and moved.

Central-station conversion of fuel to electricity releases negligible amounts of radiation and radionuclides during normal operations. Accordingly, no ecological impacts are observed from these sources. Ecological impacts of thermal pollution and from land requirements resulting from the operation of the plant are similar to those discussed for the fossil fuel plants. Table 2.12 summarizes potential effects of thermal pollution on the climate. Thermal pollution of waters, however, is approximately 50 percent greater for existing nuclear plants than for equivalent fossil fuel plants, while land requirements are usually smaller for nuclear plants.

The impacts of radioactive pollutants released from reprocessing of used fuel are negligible during normal operation. There is some concern that increased release of the radionuclide Krypton-85 resulting from expansion of the nuclear industry may have an adverse atmospheric effect. Potential effects of Krypton-85 on the climate are summarized in Table 2.12 together with those of thermal pollution mentioned above. However, more research is needed to substantiate whether Krypton will have an effect on the weather, and to assess its potential for modification of the atmosphere's electrical field, which may cause modifications of the hydrological cycle (MacCracken 1975).

Summary of Ecological Impacts

There are no detectable ecological impacts from releases of radionuclides or radiation during normal operation of the nuclear fuel cycle because of the very small quantities and activities involved. Potential ecological impacts associated with accidents and radioactive waste management were mentioned in the Introduction to this section. The modification of weather that may result from increasing releases of Krypton-85 needs further study.

The major ecological impacts are those from thermal pollution during central-station conversion; from residuals released from the use of fossil fuels to supply the required energy, particularly for uranium enrichment, central-station conversion, and transportation; and from increasing disturbance of land as larger quantities of uranium are mined to meet expanding demand and to offset decreasing availability of higher grade uranium ores.

EFFECTS OF SULFUR OXIDES AS AIR POLLUTANTS

INTRODUCTION

The scope of this study does not allow a detailed treatment of all of the pollutants produced by the energy systems. The Committee has therefore selected a single topic—sulfur oxides—for more detailed treatment, as a case study illustrating the issues involved. Sulfur oxides were considered particularly suitable for the purpose because of the magnitude of their impacts on human health and ecosystems.

HEALTH EFFECTS

Sulfur dioxide is the main sulfur oxide emitted by fossil-fuel combustion. Harm to health resulting from emissions cannot, however, be ascribed solely to sulfur dioxide (or to any other simple sulfur compound). Oxidation products of sulfur dioxide, including sulfuric acid and various suspended sulfate particulates, appear to be more toxic for humans and certain biological systems than the parent compound itself. The specific chemical species responsible for toxicity have not, however, been identified, and the levels at which pollutants are harmful to health have not been determined. The health effects of oxides of sulfur were comprehensively reviewed in a recent report by the National Academy of Sciences (NRC 1975a).

The biochemical mechanisms by which ambient concentrations of oxides of sulfur, including sulfur dioxide, sulfuric acid, and metallic sulfates, affect the lung are unknown. The major physiologic response to inhalation of sulfur dioxide is bronchoconstriction; hyperplasia of mucus-secreting cells of the respiratory tract may result from prolonged exposure to oxides of sulfur. These responses may well be explained as a reaction of sensitive tissue to acid solutions, since sulfur dioxide is a weak acid anhydride that is highly soluble in aqueous solutions.

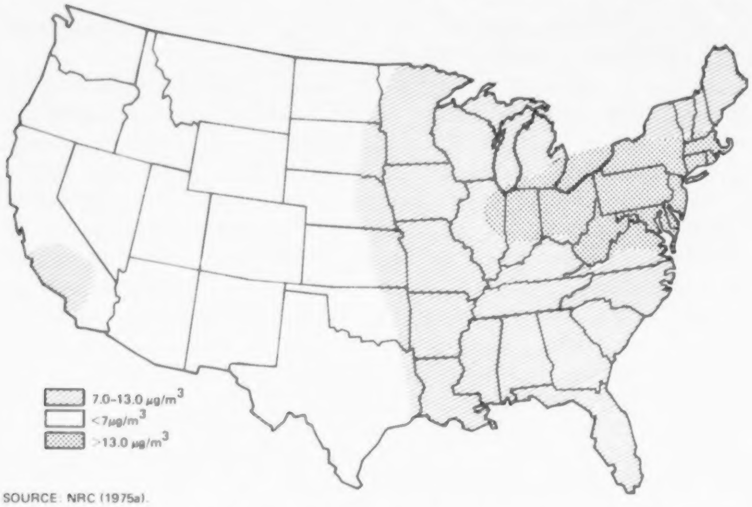
The major physiologic indicator of response to sulfur dioxide in experimental animals has been an increase in resistance to pulmonary airflow. The acute response to sulfur dioxide in animals has been short-lived, and the apparent threshold for this acute response is very high, relative to usual ambient concentrations. Pertinent data were provided from experiments by Amdur (1957, 1959, 1969) and McJilton et al. (1973) in which animals were exposed to sulfur dioxide and particulate matter, to sulfur dioxide at low and high humidity, and to sulfate particles. No effects on pulmonary flow resistance of guinea pigs were observed when animals were exposed to combinations of sulfur dioxide and sodium chloride aerosols at low humidity, but when relative humidity exceeded 80 percent, the pH of the aerosol became more acid and significant resistance to pulmonary airflow occurred. Amdur (1957, 1959, 1969) showed that aerosols of sulfuric acid and submicronic sulfate compounds were far more potent than sulfur dioxide in increasing pulmonary flow resistance in animals. The studies clearly indicate that sulfur dioxide is far less irritating than equivalent concentrations of sulfuric acid and certain particulate sulfate compounds.

Bates and Hazucha (1973) demonstrated a synergistic effect of sulfur dioxide and ozone on respiratory resistance in healthy humans. While no changes in pulmonary function were observed at concentrations of 0.37 ppm sulfur dioxide alone, inhalation of 0.37 ppm ozone alone caused a 10 to 15 percent decrement in pulmonary flow rates, and inhalation of 0.37 sulfur dioxide combined with 0.37 ppm ozone caused a 40 percent decrement. A likely explanation for the synergistic reaction is that sulfuric acid was formed by the reaction of these two compounds in the presence of water vapor in the respiratory tract, or that the decreased pH of the respiratory tract and its mucous lining enhanced the solubility of ozone and thus enhanced its effect (NRC 1975a).

Studies of the long-term effects of sulfur dioxide in animals have generally demonstrated no harm with the range of ambient concentrations (Alarie et al. 1970, 1972). In humans, however, epidemiological studies have quite consistently revealed increased mortality, higher prevalence of chronic bronchitis, greater incidence of acute respiratory disease in children, and impaired lung function in children to be associated with slightly elevated ambient concentrations of sulfur dioxide when particulate pollution is also elevated (NRC 1975a). These findings of adverse reactions in humans attributable to relatively low concentrations of sulfur dioxide have always been somewhat puzzling in view of the no-effect results of animal exposure to sulfur dioxide at much greater concentrations. Most investigators have explained the paradox by stating that sulfur dioxide was merely an index of hazardous pollution in urban atmospheres and that the sulfur dioxide/particulate complex probably accounts for the observed human effects. There is general agreement that sulfur dioxide of itself is probably relatively innocuous at ambient concentrations.

A recent series of studies relating particulate sulfate concentrations to aggravation of symptoms in asthmatics and elderly persons with heart and lung disease (U.S. EPA 1974) suggests that adverse health effects observed in humans are more likely attributable to transformation products of sulfur dioxide (sulfuric acid, sulfites, and sulfates, all indexed by particulate sulfate measurements) than to sulfur dioxide itself. The studies further suggest that adverse effects may be occurring even in communities that have not exceeded primary air quality standards for sulfur dioxide and total suspended particulates. Sulfate thresholds for adverse effects were estimated to be from 8 to 10 micrograms per cubic meter ($\mu g/m^3$) for 24-hour exposures. These estimates clearly require verification, for if they are correct, the sulfate health threshold is exceeded in a large portion of the urban areas in the entire eastern half of the United States for half the year or more, as shown in Figure 2.3. Nevertheless, in most eastern urban areas, primary air quality standards for sulfur dioxide—the precursor of man-made sulfates—have been met.

These findings have thrown doubt on the adequacy of controls for sulfur oxide emissions from large stationary sources. While sulfur emission controls may result in satisfactory levels of sulfur dioxide, they do not limit ambient levels of sulfates. There is considerable controversy over whether certain control technologies for sulfur dioxide emission, such as tall stacks or intermittent controls on power plants, may actually



SOURCE: NRC (1975a).

FIGURE 2.3 Geographical distribution of typical urban sulfate levels in the United States.

increase the sulfur loading of the regional atmosphere, and thus maintain or even increase high ambient sulfate concentrations.

The National Academy of Sciences report (NRC 1975a) on health effects and control technology for oxides of sulfur also points out the lack of understanding of the role of chemical and physical determinants in the atmospheric transformation of sulfur dioxide to sulfates. Oxidation of sulfur dioxide is accelerated by the presence of trace metals produced through stationary source fossil fuel combustion and by components of photochemical smog derived from automotive emissions. Thus, there is no direct relationship between control of sulfur dioxide emissions and sulfate levels. Complicating these relationships is the fact that atmospheric sulfates are submicronic particles capable of transport over long distance; in regions where sulfate levels are elevated largely because of distant upwind emission sources, stringent control of sulfur oxides pollutants locally may not appreciably change sulfate levels of the immediate area.

The sulfate issue is extremely important for two reasons. First, if estimates of threshold sulfate concentrations are correct, achievement of primary ambient standards for a precursor pollutant does not necessarily protect against adverse effects of products of that pollutant created by atmospheric reaction. The same consideration may apply to nitrogen dioxide and its transformation products—suspended nitrates. Second, while an ambient air quality standard for sulfates would seem to be highly desirable, there is no assurance that such a standard would protect against the health effects of atmospheric transformation products of sulfur dioxide; "sulfates" are not homogeneous substances but rather nonspecific anions which, at the same concentration, are known to be more toxic in one form (e.g., zinc sulfate) than in another (e.g., ammonium sulfate). Furthermore, current methods for measuring atmospheric sulfates may possibly give erroneous results because of reactions that might occur on the instrument used to collect particulate sulfate matter from the air. Use of sulfate concentrations as an indicator of the level of substances that affect living things may or may not prove satisfactory. Considerable toxicological and epidemiological research is required to clarify these relationships, and a body of knowledge on atmospheric chemistry of oxides of sulfur is required before an air quality standard for sulfates based on their effects on health can be formulated. The primary ambient air quality standard for total suspended particulates could be similarly scrutinized and questioned as to its efficacy in preventing adverse health effects.

Uncertainties about margins of safety and the specificity of health effects attributable to pollutants for which we have primary standards, and the lack of quantitative information for developing dose-response curves, leave us with little basis for estimating either the consequences of failure to achieve standards or the health benefits of pollution control, with its attendant resource expenditure. Whenever dose-response functions are developed in spite of these many uncertainties, the health cost of failure to control appears to be large. Table 2.13 presents data from one recent study (Finklea et al. 1975)[1] in which the health effects of increased emissions of sulfur oxides were estimated on the assumption that levels of sulfur oxides in the atmosphere would rise as a result of coal conversion or other strategies designed to cope with increased energy supply. Data on health effects presented in Table 2.13 were estimated only for the eastern half of the United States. The estimates were based on a number of assumptions and on data from 28 health studies. Among the most important assumptions were (1) that a predictable relationship between sulfur dioxide and sulfates exists, and (2) that threshold concentrations for adverse health effects were approximately 8-10 $\mu g/m^3$ for symptom aggravation and 25 $\mu g/m^3$ for mortality. Above the threshold concentration, the study assumed a linear model for the association between sulfate

[1] The quantification of the health effects of air pollutants, and even of sulfur oxides is very complex and difficult. Many health experts question the validity of this study, and the data are presented only as an illustration.

TABLE 2.13 Estimates of Adverse Health Effects from Oxides of Sulfur Exposures in the Eastern U.S. If Standards are Met or Not Met

Adverse Health Effect	Population at Risk (millions)	Estimates of Health Effects Attributable to Exposure to Oxides of Sulfur			
		Standards Met		Standards Not Met	
		1975	1980	1975	1980
Increased mortality	137.4	308	7	1,963	6,057
Days of aggravated heart and lung disease	3.7	5.3×10^6	1.2×10^6	18.3×10^6	33.8×10^6
Increased number of asthma attacks	4.1	2.5×10^6	0.8×10^6	6.8×10^6	11.5×10^6
Lower respiratory disease in children	35.2	48×10^3	0	303×10^3	888×10^3
Chronic respiratory disease symptoms in nonsmokers	31.7	12×10^3	0	223×10^3	793×10^3

SOURCE: Finklea et al. (1975).

exposure and effect. The linear model was then applied to two different scenarios for sulfur dioxide emissions to the year 1980. The first scenario assumed growth in power generation to 3.2 trillion KWh by 1980, accompanied by strict controls on sulfur oxides emissions that would permit standards to be met. The second assumed the same growth, but without further efforts to restrict sulfur oxides emissions. Under the first assumption, 7.8 million tons of sulfur oxides would be emitted from U.S. steam electric power plants in 1980, and under the second assumption, 28.1 million tons. The 1974 estimate for sulfur oxides emissions is 20.8 million tons.

Under the above assumptions, the data in Table 2.13 show that failure to meet emission standards will result in a large impact on public health expressed in excess mortality and morbidity. (Excess mortality and morbidity is the difference in these roles with no pollution control versus pollution control to the required standards.) More than 6000 deaths in 1980 in excess of what would be expected if standards were met are projected from the model, and the cumulative excess mortality between 1975 and 1980 could exceed 25,000. The excess number of days of illness aggravation experienced by elderly persons is predicted at 20-30 million days per year, and the excess number of asthma attacks would be 6-10 million per year. Each year, about 300,000-900,000 more children who are otherwise healthy would be expected to experience acute lower respiratory diseases such as acute bronchitis, croup, and pneumonia; these episodes exceed the disease experience projected if standards were met. Among adults, the model projects more than 1.5 million excess cases of chronic respiratory disease attributable to increased exposure to sulfur oxides. The projections are based on a model that has many imperfections because modifying conditions have not been specified and factored in. Nevertheless, the projections are based on the best available data.

The importance of the data presented in Table 2.13 should not be underestimated because of the uncertainty of the assumptions on which the model is based. Even if the estimates of threshold concentrations or dose-response functions prove to have overestimated the projected health impact 10-fold or even 100-fold, the impacts on human health that will result from increasing sulfur oxides emissions remain serious. The conclusion is inescapable that substantial harm to health can be expected even under quite conservative assumptions if sulfur oxides emissions are not stringently controlled. These severe consequences can be ascribed primarily to the existing high atmospheric sulfate levels throughout the eastern half of the United States and to the infinitesimal margin that appears to exist between threshold concentrations for adverse effects and current ambient sulfate levels.

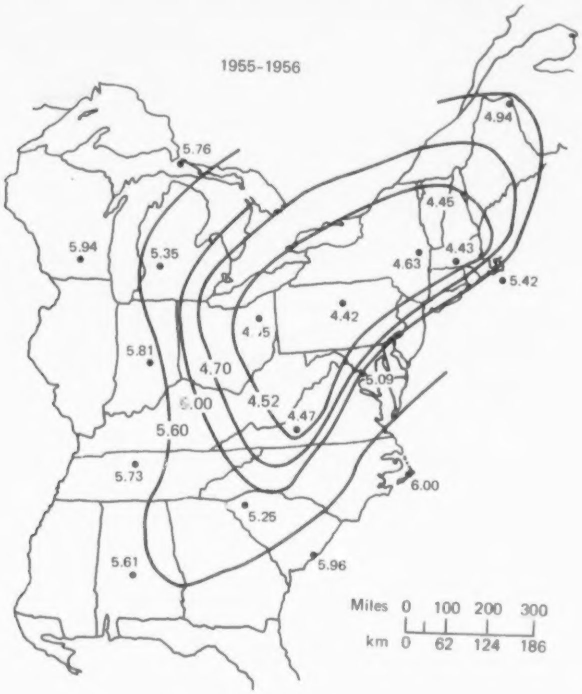
As pointed out in a recent report on Air Quality and Automobile Emission Control (NRC 1974), there is no exposure level other than zero that is attended by zero risk. We know, however, that the risks posed by some pollutant concentrations could be reasonably expected to be very small, ranging from transient irritation to possibly significant aggravation of disease in hypersusceptible persons. As the population becomes better informed on health issues, the public judgment of whether a concentration is or is not acceptable may change. Certain segments of the population are likely to run some sort of risk from any concentration of pollutants related to fossil fuel combustion. Ultimately, society will have to weigh the acceptability of these risks against the benefits of the process that creates these pollutants, and against the costs of controlling them at a given level.

ECOLOGICAL EFFECTS OF ACID RAIN

Other environmental impacts of sulfur oxides exist besides effects on human health. Stress on one component of the ecosystem may be manifested through changes in another, or even changes in an ecosystem spatially removed from the original source of stress. In any assessment of ecological effects, the effects on the immediate ecosystem must be considered as well as the potential effect on the total global environment. This is well illustrated by what has become known as acid rain.

It is now well established that rain and snow in both northern Europe and the northeastern United States have become progressively more acidic in the past two decades (Barrett and Brodin 1955, Brosset 1973, Cogbill and Likens 1974, Likens and Bormann 1974). Rain formed in an area that is relatively unpolluted would be expected to have a pH value of approximately 5.6. Recent measurements of individual rainstorms in the northeastern United States have found pH values of less than 3.0. Since pH is a negative logarithmic scale, this is a several hundredfold increase in acidity over "natural" rain. Figure 2.4 shows the predicted pH of precipitation over the eastern United States in 1955-56; predictions for 1965-66 are presented in Figure 2.5. The observed pH of precipitation in 1972-73 is shown in Figure 2.6. Three points must be emphasized in regard to these three figures: (1) variation does occur within the isolines, particularly around cities and smelters; (2) over time there has been a progressive acidification of precipitation to the west and southwest; (3) an intensification of acidity has obviously occurred in the northeastern region (cf. Dochinger and Seliga 1976).

Evidence suggests that the major source of the more acidic precipitation in the northeastern United States is air masses moving from the


1955-1956
5.76
4.94
4.45
5.94
5.35
4.63
4.43
5.42
4.42
4.[illegible]5
5.81
4.70
5.09
5.00
4.52
4.47
5.60
5.73
6.00
5.25
5.61
5.96
Miles 0 100 200 300
km 0 62 124 186

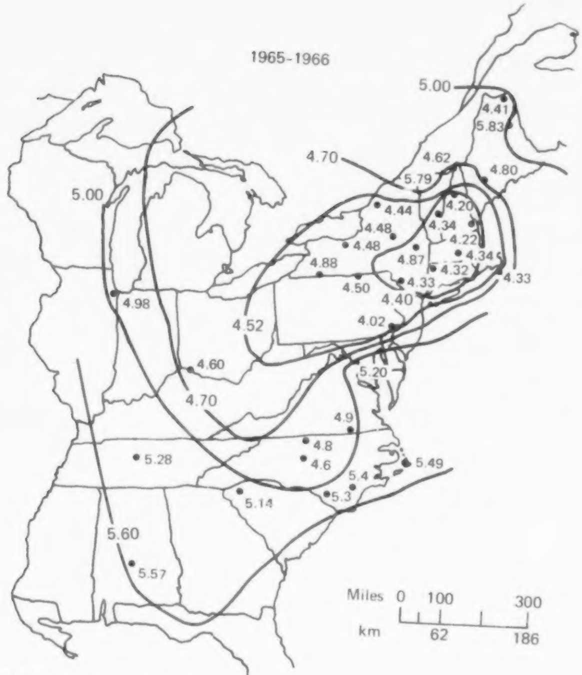
SOURCE: Cogbill, C. V. and G. E. Likens, Water Resources Research Volume 10, pages 1133-1137, 1974, copyrighted by American Geophysical Union.

FIGURE 2.4 Predicted pH of precipitation over the eastern U.S. during the period 1955–1956.

Southeast and Midwest (Cogbill and Likens 1974, 1976; Gatz 1976). The form of the acid appears to be sulfuric acid and nitric acid, with the former dominant. According to studies at Hubbard Brook, New Hampshire (Likens 1975), the sulfate contribution to the acidity was 83 percent in 1964-65 and 66 percent in 1973-74; the nitrate contribution increased from 15 percent in 1964-65 to 30 percent in 1973-74.

Effects on Soils

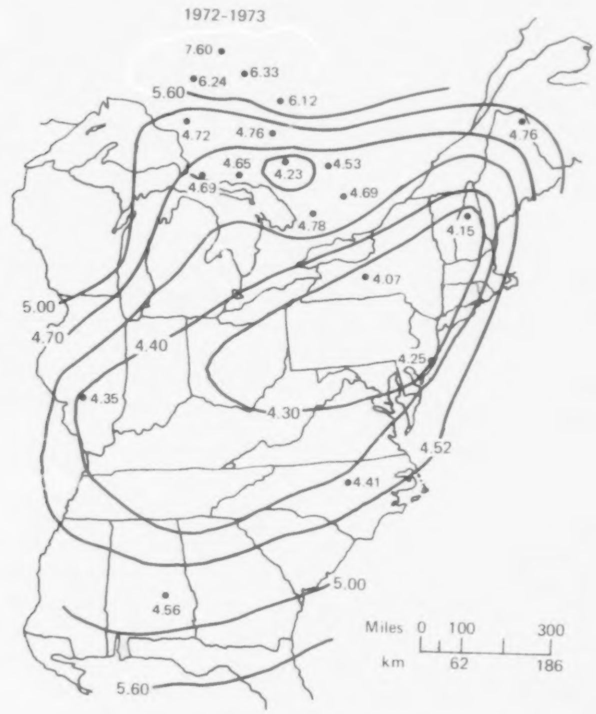
Bolin (1971) has demonstrated that acid precipitation can cause acidification of some soils. Excess hydrogen ions in the soil can cause a


1965-1966
5.00
4.41
5.83
4.70
4.62
4.80
5.79
5.00
4.44
4.20
4.48
4.34
4.48
4.22
4.88
4.87
4.34
4.32
4.33
4.50
4.33
4.98
4.40
4.52
4.02
4.60
5.20
4.70
4.9
4.8
5.28
4.6
5.49
5.4
5.3
5.14
5.60
5.57
Miles 0 100 300
km 62 186

SOURCE: Cogbill, C. V. and G. E. Likens, Water Resources Research Volume 10, pages 1133-1137, 1974, copyrighted by American Geophysical Union.

FIGURE 2.5 Predicted pH of precipitation over the eastern U.S. during the period 1965–1966.

displacement of calcium and other essential nutrients from base-exchange sites on soil particles. The extent of the damage is determined by the buffering capacity of the soils against decrease in pH and by the amounts of neutral salts deposited on the ground. Thus, calcareous soils and cultivated soils, properly managed, show relatively high buffering and low sensitivity whereas uncultivated, slightly acid, sandy soils and loams are more sensitive to acidification (Wiklander 1973/74). While in some areas the input of sulfur from acid rain may have value as a plant nutrient, in the northeastern United States it is probably of minor importance, since deposition rates are already high and soil sulfur concentrations are generally adequate to maintain productivity.


1972-1973
7.60
6.24
6.33
5.60
6.12
4.72
4.76
4.76
4.65
4.23
4.53
4.69
4.69
4.78
4.15
4.07
5.00
4.70
4.40
4.25
4.35
4.30
4.52
4.41
5.00
4.56
Miles 0 100 300
km 62 186
5.60

SOURCE: Cogbill (1975).

FIGURE 2.6 Observed pH of precipitation over the eastern U.S. during the period 1972–1973.

Effects on Agriculture

In general, few studies have been conducted on the significance of low pH for agriculture. Such work as has been done indicates that acid precipitation can do both harm and good: simulated "rain" of pH 3.2 inhibited formation of nitrogen-fixing nodules on beans, induced more rapid erosion of surface waxes on bean and oak leaves, and inhibited reproduction of root-knot nematodes (Shriner 1974).

Effects on Vegetation

A reduction in growth of coniferous forest trees of 0.3 percent per year has been reported from Sweden for the period 1945 to 1965 (Bolin 1971). This statistically observed decrease was thought to be caused by lowering of cation nutrients in the soils as a result of the increased sulfur deposition. However, since this hypothesis is not supported by experimental verification of the soil changes (Wiklander 1973/74), the reason for the decrease is not clear. Other reductions in forest growth due to acid rain have been tentatively postulated for Norway (Dahl and Skre 1971), for Hubbard Brook, New Hampshire (Whittaker et al. 1974), and for Sweden. None of the growth changes, however, can be directly attributed to acid rain. Acidity has been shown to cause increased leaching of nutrients from foliage (Eaton et al. 1973, Wood and Bormann 1975) and disruption of leaf physiology and growth (Wood and Bormann 1974).

Effects on Aquatic Systems

In Scandinavian rivers and lakes, major changes in biota have been reported to result from the acidification of the waters (Bolin 1971, Almer et al. 1974, Jensen and Snekvik 1972, Grahn et al. 1974, Johansson et al. 1973). The most striking effect has been the elimination of certain freshwater fish, especially salmon and trout. Similar occurrences have been reported in Canada (Beamish et al. 1975) and the United States (Schofield 1975). Probably the most dramatic effect of acidification of waters has been reported for five lakes in Sweden (Grahn et al. 1974). Their study reports the invasion of lakes by *Sphagnum*, a plant that normally grows on land, as waters become more acidic. This encroachment results in deterioration of bottom fauna, a shift from bacterial to fungal decomposition, accumulation of organic matter, and a decrease in total fish biomass. In general, the lakes change from eutrophic (high fertility) to oligotrophic (low fertility), and acidification is accelerated.

Effects on Materials

Acid precipitation can also increase weathering of buildings and corrosion of metal objects.

In summary, precipitation has become more acid over the past 20 years in the eastern United States. The acid precipitation is caused primarily by sulfuric and nitric acids formed from the combustion products of fossil fuels. Effects of the release of the combustion products may be observed hundreds of miles from the point of release. Research to assess potential impacts of acid rain is at an early stage, but studies being conducted in Scandinavia and North America already indicate the potential for widespread impacts that could have severe ecological and economic consequences.

CONCLUSION

This chapter's review of environmental effects of energy systems has shown that the production and consumption of energy potentially poses a grave threat to human health and to the ecology. The impacts from energy residuals include impaired health, damages to the ecological systems, and increasing material damage and lost production. Even though the risks are difficult to quantify, they are clearly worth reducing. The health effects of the emission of sulfur dioxide (and associated pollutants) from fossil-fuel cycles, and ecological damage resulting from acid rain, appear to be particularly serious problems. Not only are individual impacts important, but the synergisms among pollutants increase cause for concern.

There is controversy over the proper limits of pollution control. Many factors must be considered to determine the best means of reducing pollution and the extent to which environmental protection should modify other important national goals. A central question for this report is how much regulatory effort, money, and energy should be devoted to protecting the health of consumers while providing them with sufficient energy. The next chapter discusses a series of issues selected from the energy systems impact matrix. In these issues we explore the necessary trade-offs between avoiding the serious environmental consequences outlined in this chapter and refraining from excessive impediments to meeting energy needs.

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3 Major Energy/Environment Issues

INTRODUCTION

The deepening crisis in energy cannot be separated from considerations of environmental concern. A knowledge of the economic and energy costs associated with controls, and an estimate of the uncertainty involved in assessing those costs, is a necessary basis for effective decision making on environmental protection. In its investigation of the contribution of environmental regulations to the current and long-term energy crisis, the Committee has limited its study to federal regulations that aim primarily to protect human health and the environment, with emphasis on the energy costs associated with the fossil and nuclear fuel cycles.

The Committee drew on several evaluations of the incremental economic costs of environmental regulations (CEQ 1976a, Perl 1976, U.S. EPA 1974c, Bailly et al. 1974, and an oral communication from Harry Perry of Resources for the Future, November 11, 1976). Incremental costs for pollution control are defined as expenditures made pursuant to federal environmental legislation beyond those that would have been made in the absence of this legislation. (Total environmental costs are usually double the incremental costs.) The costs include operating and maintenance costs as well as interest on and depreciation of equipment and facilities. The assumptions, methodologies, quality of data, and comprehensiveness of the estimates vary widely. The range of incremental costs is between 1 and 1.5 percent of the gross national product.

The most comprehensive assessments of the annualized costs of environmental regulations are those made by the Council on Environmental Quality (1976a). They estimated total annualized costs in 1975 at $31.7 billion with incremental costs at $14.4 billion. For a gross national product of about $1400 billion these costs are about 2 and 1 percent respectively. (All costs and gross national product figures are in 1975 dollars.)

The estimated annualized costs for 1984 (CEQ 1976a) are about $40 billion, and incremental costs are about $20 billion. The projected gross national product for 1984 is about $1900 billion (CEQ 1976a) so that the total and incremental environmental costs remain about 2 and 1 percent of gross national product. The estimates by CEQ parallel closely the estimates by EPA (1974c) and provide the lower boundary of the range. (These estimates are also close to those of Leontief [1977], who found that with current commercially available abatement technology, pollution is not an unmanageable problem. Leontief concluded that the overall economic costs of pollution control, even if relatively strict abatement standards were to be applied gradually to developing regions, would not exceed 1.5 to 2 percent of gross national product.)

The high boundary of the range is provided by estimates by National Economic Research Associates (NERA) (Perl 1976) for annualized total pollution control costs for 1983 of $55.2 to $66.1 billion (1974 dollars) and another estimate of $78.5 to $89.4 billion (1975 dollars). The estimates are based on NERA's numbers for electrical utilities (Perl and Fitzgerald 1975, 1976a, 1976b) and the data on water pollution control costs from the National Commission on Water Quality (NCWQ 1975) which are much higher than those of CEQ. These assessments yield total annualized costs of about 3 to 4.5 percent, and incremental costs of about 1.5 to 2 percent.

More interesting to the Committee, but at the same time much more difficult to assess, were the incremental energy costs of environmental regulations. In the imperfect energy markets of today, large gaps exist between the marginal costs and the average prices of energy. The gap is largely created by controls and subsidies applied to energy prices, and by the failure to internalize all the social and environmental costs of energy production. Projections indicate that the gap will continue to widen.

The Committee found the data base for estimating energy costs of environmental regulations very poor. Fewer studies were available than for the economic costs, and they were more difficult to compare because of the different underlying assumptions (Davidson et al. 1975, Hirst 1973, Bailly et al. 1974, Sheppard et al. 1976, an oral communication from

Harry Perry of Resources for the Future, November 11, 1976, and an unpublished report by J. Heller, 1974[1]).

In its evaluation of the available studies, the Committee concentrated on the energy impacts of the following key pieces of environmental legislation: Clean Air Amendments (1970), Federal Water Pollution Control Act (1970), Solid Waste Disposal Act (1970), Resource Recovery Act (1970), National Environmental Policy Act (1969) with special emphasis on the Mineral Leasing Act of 1920, OCS Lands Act of 1953, Mining and Minerals Policy Act of 1970, Alaska Native Claims Act of 1971, Atomic Energy Act of 1965 and amendments, and state strip-mining laws passed in view of pending federal legislation in 1977, such as the Mineral Leasing Reform Act and Surface Mining Reclamation Acts.

The different studies provided a range of incremental energy costs of environmental regulations of 1 to 3 quads of energy, or about 1 to 4 percent of the 1976 total energy consumption of about 75 quads.

In the judgment of the Committee, a reasonable rough estimate of the 1983 incremental energy requirements of environmental regulations is between 2 and 3 quads or about 2 to 3 percent of projected total energy consumption of about 100 quads. The numbers were obtained from assessing and combining incremental costs of the major environmental regulations mentioned above. The range of 2 to 3 percent is approximate, and would be affected by a change in any of the assumptions. For example, the strict standard of 1.5 to 2 g/mile now in force in California means a fuel penalty of 10 percent for California cars. If the stricter California standard replaced the current requirement of 3.1 g/mile for the whole country, with today's mix of cars and engines, the incremental energy penalty would amount to 1.5 percent of the national energy consumption. Other assumptions may appreciably reduce this penalty. Thus, a modification of this critical assumption alone may affect our projected incremental energy costs by about 50 percent.

The incremental energy costs of environmental regulations are significant, but not overwhelming. Other socioeconomic factors such as energy costs relative to other costs, demographic and cultural variables, and government policies including taxes, subsidies, and regulations have much larger effects on energy consumption and waste. A recent study (Schipper and Lichtenberg 1976) concluded that the lower per capita energy consumption in Sweden (over a third lower than that of the United States) can largely be attributed to differences between the policies of the two countries' governments relating to transportation and

[1] J. Heller (1974) Economic Impact, Energy Requirements and Effluent Reductions in Phase I Industries Due to Best Practicable Control Technology Commercially Available. Unpublished report.

insulation of houses. (The two countries are closely comparable in the relevant matters of gross national product, quality of life, industrialization, and population density.) Another recent study (Lovins 1976) estimated that it is possible to double end-use efficiency of energy consumed by the end of the century through the implementation of technological substitutions, which are not only feasible, but also significantly more cost-effective than increasing energy production. Other proposals involve changes in resource use that would entail changes in life styles, and improved methods of resource extraction and recycling.

It is far more important to reduce energy consumption than to save energy by delaying implementation of environmental regulations. The Committee concluded that the energy and economic costs for the nation of keeping pollution within manageable limits are small when compared to the costs of the energy systems, the amounts of produced energy, or potential savings in energy to be realized by increasing the efficiency of supply systems.

The Committee was impressed by the scope and gravity of environmental hazards (see Chapter 2). It concluded, however, that available data do not provide a reliable quantitative basis for relating the costs of environmental regulations to their health and environmental benefits. Nonetheless, sufficient evidence was mustered to reply to the three major questions implied in the Congressional concern that was the impetus for this report: (1) To what extent is a choice forced between the availability of energy and the maintenance of environmental quality? (2) How efficient and cost-effective are current federal pollution control regulations? (3) What are the major trade-offs among health, environmental quality, energy, and economic factors in federal regulatory decision making?

In answer to the first question, the Committee concluded that for the nation as a whole, the energy costs of environmental regulations do not force a choice; goals of both energy production and high environmental quality may be achieved simultaneously. On the micro level, local or regional situations may be such that an environmental regulation may prove too costly in terms of energy, and is hard to justify. For such cases, the Committee recommended flexibility in the implementation of the regulations: for instance, waivers for old, low-load power plants in rural areas (Issue 4), delays in closed-cycle cooling requirements for power plants (Issue 3), and more innovative approaches such as the "emission offset strategy" proposed by EPA (Chapter 4).

To gain insight into the cost-effectiveness of environmental regulations, the Committee examined the seven major issues discussed below, and found valid reasons to question some of the current control strategies. Some of the regulations were found to suffer from lack of a comprehensive and systematic approach (see Issues 1, 2, and 5). Another shortcoming that lessened cost–effectiveness was found to be lack of coordination between agencies with overlapping responsibilities (see Issues 1, 5, and 6).

To improve the cost–effectiveness of environmental regulations, the Committee recommended a holistic approach instead of the focus on a single pollutant, single source, or single environmental medium exhibited in some of the issues examined by the Committee. A balanced approach in which efforts are directed toward controlling the major sources of pollution also contributes to cost–effectiveness. Continuing improvement of the effectiveness of control is important not only to save money and energy but also to minimize risks to human health and the environment.

A better data base for regulations, and fuller consideration of all the trade-offs involved in regulations were also recommended. The most common trade-offs involved in environmental regulations are those of economic and energy costs versus health and environmental benefits. Other kinds of trade-offs illustrated by the seven issues evaluated in the chapter are risk versus risk, health versus the environment, and time to achieve environmental quality versus overly restrictive regulations.

Risk versus Risk. "As low as practicable" radioactive emission regulations aim to decrease the exposure of employees and the public to radiation from nuclear plants. However, they may expose people to greater risks from accidents during start-up and shut-down of the reactor (Issue 5).

Health versus the Environment. As a rule, deep coal mining creates more risks to health while surface mining is more harmful to the environment. Environmental regulations should strive to achieve a balance between these two kinds of risk (Issue 6).

Time to Achieve Environmental Quality versus Overly Restrictive Regulations. Auto emission standards provide an example of the need for careful balancing. On the one hand, too lenient regulatory requirements result in inaction on the part of the industry. On the other hand, too restrictive auto emission standards for oxides of nitrogen may eliminate the diesel engine or delay the introduction of other alternative engines that promise higher efficiency and better control of the emission of other pollutants (Issue 2).

The seven issues dealt with by the Committee and discussed below are: pollution from oil and gas production in offshore waters; automobile emissions; thermal water pollution; control of sulfur dioxide emissions from electric power plants; "as low as practicable" radioactive emissions;

surface coal mining and the National Environmental Policy Act; and prevention of significant deterioration of air quality.

Our discussions have been kept brief so that an overview of the seven issues could be presented concisely. Supplementary material is included in the Working Papers (see List of Working Papers in the Front Matter); the references at the end of the chapter can be used to find still further information.

ISSUE 1
OIL AND GAS PRODUCTION IN OFFSHORE WATERS

STATUTORY STATUS

The Federal Water Pollution Control Act (FWPCA) Amendments of 1972 (33 USC 1251 et seq. 1973; PL 92-500) Sections 301 and 304 contain provisions relating to the regulation of effluents from extraction of offshore petroleum and natural gas. EPA developed two sets of uniform effluent guidelines. The first set, for best practicable control technology currently available (BPT), is to be applied by 1977. The second set, best available technology economically achievable (BAT), is to be applied by 1983 (U.S. EPA 1975a). The guidelines were developed for two areas offshore: the near-offshore (state waters usually within three miles) and the far-offshore (federal waters usually beyond three miles) also termed outer continental shelf (OCS).

EPA considered various alternatives to regulate pollution from far-offshore oil and natural gas production. The present guidelines recommended by EPA are 72 ppm of oil for BPT and 48 ppm for BAT. The zero-discharge alternative goal initially considered for 1983 has been abandoned by EPA for far offshore because it was adjudged excessively restrictive and economically impractical. Within the near-offshore area, where there was a potential though very small risk to some shoreline and estuarine ecosystems, EPA mandated retention of the BAT requirements of zero discharge. This means reinjection of produced waters and progress toward the national goal of eliminating the discharge of all pollutants. These proposed regulations for near- and far-offshore oil and gas production are under review, allowing time for consideration of the various public comments. EPA expects a final decision during 1977.

DISCUSSION

The residual of main concern from offshore oil and natural gas production is the oil in the discharged brine formation water. Estimates of its oil content range from one to four tons of oil per million barrels of oil produced (Kash et al. 1973). In order to remove some of the oil residue from formation water, the water is conventionally passed through an oil–water separator before discharge.

Alternatives to the discharge of near-shore formation water to the sea are reinjection to the original oil well (EPA's definition of reinjection) or to a disposal well, or pipelining to the shore for treatment. For economic and environmental reasons, reinjection is generally preferable to shore treatment of near-offshore formation water.

Reinjection into the oil well may be practical when it crosses suitable geologic strata (such as water-bearing strata), or to replace exhausted oil at a certain level. Otherwise, reinjection involves the added costs of drilling additional wells for the disposal operations and the operation and maintenance of the disposal system. These requirements are reflected in higher operating costs, in energy expended to run reinjection processes, and in some cases in lost recovery of economically marginal oil and natural gas reserves. (To provide a better understanding of environmental benefits that accrue from meeting EPA's zero-discharge regulations for offshore waters and of costs involved in that compliance, an analysis of the problem is presented in Appendix C.)

Formation waters currently contribute less than 0.2 percent of the input of total petroleum hydrocarbons into the sea, according to estimates by a National Academy of Sciences report (NRC 1975b). In contrast, automotive waste oil accounts for about 26 percent, non-marine industrial operations and tanker operations each for about 22 percent, natural seepage for about 15 percent, and vessel accidents for about 5 percent. As a result, other readily identifiable man-made sources may have several hundred times the impact of offshore oil formation water. (See Table 3.1 on sources of crude oil and petroleum products discharged into the ocean.)

Few studies have been conducted on the effects of operational discharges of petroleum to ocean waters, though one such study is being promoted by the Economic Analysis Division of EPA. There are, however, some observational and limited experimental data, and these indicate that offshore platforms have little impact upon the ecosystem or marine resources. Exceptions to this rule may occur in particularly susceptible near-offshore areas such as coastal areas with low-lying shoreline, enclosed bays, and marshlands which are usually production grounds of marine resources. Two recent studies in areas subjected for many decades to petroleum drilling and production—the Gulf Coast (Morgan et al. 1974) and Lake Maracaibo, Venezuela (Templeton et al. 1975)—support the above rule.

TABLE 3.1 Sources of Crude Oil and Petroleum Products Introduced Into the Ocean Each Year[1]

Source	Amount (metric tons)
Tanker Operations	
LOT[2] cleaning and ballasting	84,499
Non-LOT cleaning and ballasting	455,708
Product tankers using store reception facilities	19,492
Product tankers not using store reception facilities	63,832
Ore, bulk, and oil carriers cleaning and ballasting	119,543
Additional cleaning and disposal prior to drydocking	91,895
Tanker bilges	9,573
Tanker barges	12,787
Terminal operations	31,933
Total from these sources	889,262
Other Ship Operations	
Bunkers	9,055
Bilges, cleaning, ballasting	292,481
Total from these sources	301,536
Vessel Accidents	
Tankers and tank barges	124,071
All other vessels	48,972
Total from these sources	173,043
Offshore Production	
Total	118,126
Natural Seepage	
Total	600,000
Nonmarine Operations and Accidents	
Refinery and petrochemical plant waste oils	195,402
Industrial machinery waste oil	718,468
Automotive waste oil	1,034,488
Pipelines	25,574
Total from these sources	1,974,032
Overall total	4,055,999

[1] One metric ton equals about seven barrels.

[2] LOT, load on top, is an oil loading technique which minimizes the disposal of oily water ballast into the ocean.

SOURCE: Travers, W. B. and P. R. Luney (1976) Drilling, tankers, and oil spills on the Atlantic Outer Continental Shelf. *Science* 194(4267):791–796. (Copyright 1976 by the American Association for the Advancement of Science.)

Thus, in the absence of any observable damage to the environment from offshore production waters and in the face of much larger quantities of petroleum residuals from sources other than offshore wells, there would seem to be no discernible environmental benefits from requiring zero discharge of even near-offshore formation waters. (The proposal for zero discharge is in fact being reviewed by EPA.) Only where there are estuarine areas in close proximity to production activities or where significant natural collector mechanisms (such as eddies, tides, or currents) are at work is there likely to be potential for adverse impacts, and accordingly, for considering tighter environmental regulations.

Estimated costs of zero discharge limits for oil are taken from Cross et al. (1975) and A.D. Little, Inc. (1975). The results of these studies are not exactly comparable, but taken together they indicate that capital costs for zero discharge could amount to $1 to $3 billion by 1983. Operation costs could total $100 to $200 million per year. In addition, significant requirements of energy and steel could be expected. While the conditions under which these studies were conducted make it unwise to treat them as more than gross estimates, it remains evident that large expenditures of capital and energy are required for reinjection of formation waters.

The offshore oil production issue essentially reduces to these considerations: (1) there are no generally proven environmental benefits to be gained from tight controls; (2) oil from formation waters that results from the production of offshore petroleum and natural gas, particularly after undergoing separation, is usually only a small fraction of other anthropogenic and natural sources of pollution; and (3) costs of compliance with currently proposed regulations and particularly with those calling for best achievable technology economically available are high. Therefore (4) the regulatory approach to formation waters should avoid mandating compliance with regulations simply because they are technologically feasible when, at the same time, they involve prohibitive costs and yield no tangible benefits. Instead, consideration should be given to the nature of the regional ecosystem which is potentially affected and to more cost-effective alternatives (if needed) for controlling other sources of oil pollution from tanker spills, urban and industrial run-off, and atmospheric deposition.

CONCLUSIONS AND RECOMMENDATIONS

An analysis of the EPA strategies for controlling the effluents from the production of oil and gas in offshore waters shows that the current regulatory policy is motivated by technological capability rather than by proven environmental necessity. The Committee's studies lead to the conclusion that while the dollar and energy costs of existing and proposed EPA regulations for controlling effluents in offshore waters are not disruptive or unreasonably large relative to other expenses borne by the industry, they are generally not cost-effective or even necessary. There is little evidence to justify zero-discharge technology except for particularly susceptible areas near shore-line and estuarine boundary grounds (though even this need has not been conclusively validated).

When best practicable technologies are used, the residuals from offshore oil production seem harmless and trivial in comparison with other sources of oil contamination of coastal waters, such as tanker spills, urban and industrial runoff, and atmospheric deposition.

The offshore pollution control issue is a good example of a situation in which a better balance should be established between considerations involving the economy, energy, and the environment. In conclusion, the Committee suggests a review of the Federal Water Pollution Control Act Amendments of 1972 in the case of offshore oil and gas production. (The Agency is now considering changes to the OCS Oil and Gas Effluent Guidelines, which have been remanded by the courts back to EPA). A correction in policy is recommended.

ISSUE 2
AUTOMOBILE EMISSIONS

INTRODUCTION

The regulation of automobile exhaust emissions illustrates the complexities involved in balancing health, environmental quality, energy, and economic factors.

The automobile is an important contributor to urban air pollution. Recent estimates (CEQ 1975) for 1974 attributed to transportation sources about 75 percent of carbon monoxide (CO), 45 percent of oxides of nitrogen (NO_x), 40 percent of hydrocarbons (HC), and 5 percent each of particulates and of sulfur dioxide (SO_2) of total air pollution. Although average emissions per vehicle mile have been decreasing since 1970, total vehicle miles traveled have been increasing. Altogether, no significant decreases in the absolute or relative contributions of the transportation sector to the total emissions of the major air pollutants were reported by CEQ (1975) for the period 1970-1974. The control of automotive sources of CO, NO_x, and HC is clearly critical of any program designed to improve the quality of the air.

At the same time, the transportation sector accounts for a major share of the nation's energy demand (about 25 percent in 1976) and is a significant part of the gross national product and employment. Constraints on the design and production of automobiles in the form of emission regulations risk energy penalties and economic disturbances. It should, however, be noted that automobile emission regulation is only one of many factors affecting fuel economy. Among others are weight, convenience features, aerodynamic drag, type of tires, lubricants, horsepower-to-weight ratios, engine and transmission design, and power sources. It has been estimated (Wildhorn et al. 1976) that by mandating feasible improvements in weight and technology standards it is possible to conserve up to 40 percent of annual gasoline consumption, a saving that more than compensates for reduced fuel economy attributable to emission standards.

The most obvious means of improving air quality and reducing energy demand is to decrease the number of vehicle miles traveled; the less fuel burned, the less exhaust emission from any engine system. This concept is a part of the air quality achievement plans of many regions.

Transportation accounted for over half of the oil consumed in 1976 (Exxon 1977), and this share is expected to increase as electric utilities shift from oil to coal and nuclear energy. A large portion of the oil consumed by automobiles is imported, and oil imports are projected to increase from 44 percent of supplies in 1976 to about 50 percent by 1980. (Exxon 1977).

The critical issue is how to select among alternative pollution control strategies so as to protect human health at least cost in dollars and in fuel penalties arising from control equipment. Among the most important questions to be resolved in the selection are how stringent to make the emission standards, how rapidly to implement them, and how to provide an incentive for industry to improve performance of automobiles.

The Clean Air Act Amendments of 1970 (42 USC 1857 et seq. 1970; PL 91-604) specify a reduction of 90 percent from the 1970 emission levels of hydrocarbons and carbon monoxide, and the 1971 levels of oxides of nitrogen. This reduction was to be achieved by 1975 and 1976 respectively. The numerical standards which define (in grams per mile) the maximum permissible emission levels of unburned HC, CO, and NO_x from the exhaust of automotive vehicles were set after EPA established a test procedure for measuring these pollutants. The Act specifies decreasing emission levels to be achieved in coming years, but Congress authorized one-year delays in 1973 and again in 1975 in the imposition of these standards, instead setting interim standards.

The 1976 federal standards for light-duty vehicles are 1.5, 15, and 3.1 g/mile for HC, CO, and NO_x, respectively. (The law allows California, which had enacted its own laws before the federal law, to set more stringent requirements. Standards of 0.9, 9, and 2.0 g/mile were operative in California in 1976.) Statutory standards to be met by 1978 call for 0.41, 3.4, and 0.4 for the three pollutants, with an intermediate value of 2.0 for oxides of nitrogen required in 1977. (Pending legislation provides for delay in imposing these standards until 1979 for HC and CO and until 1980 for NO_x.) The Act also gives EPA the authority to regulate fuel additives and to phase out lead additives from gasoline.

THE POSITION OF INDUSTRY

The auto companies argue that the air quality standards are designed to protect human health under very conservative assumptions. The industry claims that the data on health effects, on which the standards are based, are too imprecise, and that the assumed approach of meeting the worst case is wasteful. The auto industry has almost universally adopted the catalytic converter as the major tool for meeting current standards for hydrocarbons and carbon monoxide.

This has enabled partial recovery of the gas mileage loss of previous years by permitting the adjustment of the engine for efficiency rather than the settings previously used to meet emission standards in the absence of a catalyst. Some further reductions in HC and CO are feasible by employing an air pump to increase the oxidation efficiency of the catalyst. The industry states, however, that additional engineering developments will be necessary in order to reduce the significant emissions that take place before the catalyst reaches operating temperature. This "cold-start" phase of the EPA driving cycle for automobiles currently accounts for half the hydrocarbons and carbon monoxide emitted by catalyst-equipped cars (U.S. DOT 1976).[2]

Industry has attempted to meet the current oxides of nitrogen standard mainly by lowering the engine compression ratio and by recirculating the exhaust gas (termed EGR). Both steps lower peak temperature in the engine. The industry maintains that further tightening of the standards will further reduce engine efficiency (leading to lower gasoline mileage) and raise the cost of cars by adding to their control equipment. Car producers point to the 10 percent reduction in gasoline mileage now being experienced in California as compared to the rest of the nation, as a consequence of the more stringent California standards; and they

[2] Elder, C.J. et al. (1976) Testimony given by C.J. Elder et al. of General Motors at meeting of the Panel on Automobiles of the Committee on Energy and the Environment, April.

estimate that an additional 10 to 15 percent may be lost if the full statutory standards are imposed.[3]

Research to develop alternative, high-efficiency engines is being conducted in the laboratories of the automobile manufacturers, but the industry claims that existence of the oxides of nitrogen statutory standard (0.4 g/mile) discourages the development of such engines because even they cannot meet these NO_x limits.

The catalytic converter introduced for oxidizing hydrocarbons and carbon monoxide to harmless CO_2 and water can produce as by-products sulfur oxides and sulfuric acid mist (from the sulfur in gasoline). To assess the seriousness of the sulfate problem, General Motors conducted a test with a fleet of catalyst-equipped cars to determine their contribution to the atmospheric sulfur oxide levels. According to General Motors, these studies show that sulfur oxide emission controls are unnecessary (Stevens et al. 1976, U.S. Congress, House 1976c).

Because reduced compression ratios are now being employed in automotive design, the industry foresees no need for higher octane ratings than are currently available in unleaded fuel. However, the susceptibility of catalysts to lead poisoning requires that virtually all gasoline sold will have to be lead free as the national fleet becomes equipped with catalysts. The position of the oil industry is that while the current modest quantities of unleaded fuel can be supplied by selective blending of refined components, a significant capital investment in new refinery facilities will be required to supply the larger quantities of lead-free gasoline. Removal of almost all the sulfur at the refinery is conceded to be technically feasible, but it would carry a price tag of several billions of dollars (Sheppard et al. 1976) if applied to all U.S. gasoline production. For that reason industry believes the removal of sulfur at the refinery is unwarranted.

THE POSITION OF EPA

EPA recognizes the automobile as a major contributor to air pollution. The Agency supports the position of stringent emission standards for passenger automobiles, and the timetable set by the 1970 Clean Air Amendments for imposing them. Substantial improvements in air quality have resulted from implementing the automobile emission standards, and EPA would like to ensure continuing improvement in ambient air quality. With the introduction of the catalyst in 1975, a strategy of improving automobile emissions in concert with fuel economy objectives has become possible.

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[3] See note 2 above.

EPA in the past has favored legislation which would require the attainment of statutory standards for HC and CO by 1982, and which would give its Administrator flexibility in setting the 1982 NO_x emission standard. The Agency recognizes the need to pursue a strategy of coordinated control over all sources of the above pollutants, including stationary sources, gasoline marketing, and other mobile sources. The fact that older polluting cars are being continually replaced with much cleaner cars, and the short time for the introduction of additional emission control innovations, tend to make pollution from automobiles more feasible to control than that from many stationary sources.

Auto emissions are one area where Congressional mandates have prevented EPA from basing its regulations on cost–benefit assessments or on cost–effective trade-offs between pollutant control and other environmental or energy factors. EPA still seeks flexibility in the implementation of the emission standards within the current legislation set by Congress (Clean Air Amendments of 1970, 42 USC 1857 et seq. 1970; PL 91-604).

EPA considered introducing a sulfuric acid emission standard in March 1975 when there was concern over these emissions from cars newly equipped with catalysts. The Agency's concern continues despite the study conducted by General Motors, because EPA is cautious about drawing far-reaching conclusions from that single test. EPA is sponsoring more comprehensive and representative freeway tests to evaluate the contribution of sulfates from catalyst-equipped automobiles. The current position of the Agency, however, is that no sulfuric acid emission standard is necessary.

DISCUSSION

Emissions of Oxides of Nitrogen (NO_x) *and Hydrocarbons* (HC)

At present about 45 percent of man-made emissions of oxides of nitrogen in the nation as a whole result from transportation, while 55 percent arise from stationary sources such as power plants or industrial boilers (CEQ 1975, NRC 1975a). This situation is projected to change in the near future: nationwide NO_x emissions are expected to increase substantially in the next five to ten years, primarily because the number of stationary sources is expected to grow. Unfortunately, technology to control NO_x is not yet available for many categories of stationary sources. Aggregate nationwide data and annual average of pollutants should not obscure the fact that local, short-term concentrations to which people are actually exposed are the important considerations in protecting human health.

Oxides of nitrogen are formed by reaction of nitrogen with oxygen within the combustion chamber. In the case of the automobile, the amount of oxides of nitrogen produced from combustion can be limited by four methods. One method is to lower the temperature within the engine by lowering the engine compression from ratios as high as 11:1 to today's typical ratio of 8:1. A second method limits the amount of air in the combustion zone. This approach carries the risk of incomplete combustion of the fuel, leading both to a loss of heat energy and to increased emissions of carbon monoxide and hydrocarbons. A third method, recirculation of exhaust gas back into the combustion zone, is widely used to dilute the gasoline/air mixture and, in so doing, to reduce the average engine temperature. This is an important technology employed in the automotive industry for control of oxides of nitrogen. A fourth method that is beginning to enter the market is the use of a three-way catalyst.

In all heat engines, such as the conventional Otto internal combustion gasoline engine, the temperature of the working fluid is an important factor in determining energy conversion efficiency. Therefore, a reduction in compression ratio to effect lower cylinder temperature carries with it an energy efficiency penalty. By employing exhaust gas recirculation in addition, most internal combustion engines meet a standard of about 2 g/mile of oxides of nitrogen. The fuel penalty of these controls is estimated to be approximately 10 percent compared to precontrol cars. Since automobiles consume almost 15 percent of the energy in the United States (U.S. DOI 1975b), a 10 percent penalty represents about 1.5 percent of the national energy consumption.

The three-way catalysts may be used to meet the 1978 oxides of nitrogen standards of 0.4 g/mile. (Volvo has certified a three-way catalyst for 50,000 miles of life. The catalyst contains rhodium, and reportedly obtains better mileage than the current model.) Questions of cost and durability of the catalyst remain, and periodic inspection would probably be required to ensure catalyst effectiveness.

There may be technological costs associated with meeting the statutory standards for oxides of nitrogen. Several alternative engines (stratified charge, diesel) may be able to meet today's standards without a catalyst and with good fuel efficiency (U.S. DOT 1976). However, these engines cannot possibly comply with the 1978 oxides of nitrogen limits without either lower efficiency or a reduction catalyst. Thus, the timing of compliance may inhibit the introduction and trial of some technological alternatives to the conventional Otto cycle engine.

In the case of hydrocarbons, automotive emissions contribute heavily to the concentrations of this pollutant in the atmosphere. In fact, if evaporation losses associated with gasoline marketing are included, the transportation sector accounts for about 70 percent of man-made hydrocarbon emissions (Bentz and Galvis 1975). The second largest source is industrial evaporation of solvents, which accounts for an additional 20 percent. (These evaporative losses are wasteful of oil products, and their elimination would, therefore, conserve energy as well as provide further HC reduction. In fact the high price of petrochemicals has already led to many industrial installations of solvent recovery systems.) There are also several natural sources of hydrocarbon emissions, including terpenes emitted from some types of pine trees, seepage from petroleum and natural gas fields and geothermal areas, and forest fires. But all natural sources appear to play only a minor role in urban pollution except under unusual meteorological conditions (Saunders et al. 1974).

Because hydrocarbon emissions from automobiles constitute so large a part of total hydrocarbon levels, and because hydrocarbons are a major contributor to the formation of nitrogen dioxide and oxidants from nitric oxide, a major effort to improve air quality should include stringent limitations on automotive hydrocarbon emissions.

The current state-of-the-art in the automotive field offers an oxidation catalyst to burn off the hydrocarbons (and carbon monoxide) emitted from the engine. This catalyst has about a 90 percent conversion efficiency once it has come up to operating temperature (U.S. DOT 1976). Unfortunately, it is during the first minute or two of the 20-minute EPA test driving cycle that half the total test hydrocarbons/carbon monoxide are emitted from catalyst-equipped cars (U.S. DOT 1976).[4] Thus, the higher catalyst efficiency that is feasible with increased airflow will not help much unless the cold-start problem can be solved. Because emission of hydrocarbons is primarily the result of an unburned boundary layer at the walls of the engine's cylinders (U.S. DOT 1976) while carbon monoxide results from incomplete oxidation throughout the volume of gasoline in the cylinders, different reductions of these constituents are likely with any control solution. For example, there are indications that the "cold-storage" (U.S. DOT 1976) approach to avoiding cold catalyst emissions may be effective for hydrocarbons but not for carbon monoxide. It should also be noted that oxidation of incomplete combustion products by a catalyst does not directly contribute to engine efficiency, but can increase efficiency indirectly by freeing the engine of certain demands that would otherwise be made for emission controls.

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[4] See note 2 above.

The oxidation catalyst appears to offer a good solution to hydrocarbon control. The basic equipment currently is installed on new automobiles, and increased catalyst efficiency can be obtained with relatively small marginal costs. It appears, therefore, that statutory hydrocarbon standards can be met without incurring significant costs in energy, money, or technological investments.

Complex photochemical reactions occur among the emissions of NO_x and HC and the various constituents of the atmosphere. The reaction products are nitrogen dioxide, oxidants whose major component is ozone, nitric acid, and nitrates, which are the major damaging constituents of smog.

To formulate cost–effective oxidant and NO_x abatement strategies, some understanding is required of the processes and factors that influence the conversion and transport processes and the interaction of NO_x with atmospheric oxidant/HC. The present state of knowledge is very incomplete and urgently needs improvement; nevertheless, some useful and valid deductions can be made. The situation can be summarized by the following simplified reactions:

$$NO + O_3 \rightarrow NO_2 + O_2 \tag{1}$$

$$NO_2 + \text{sunlight} \rightarrow NO + O \tag{2}$$

$$O + O_2 + M \rightarrow O_3 + M \tag{3}$$

$$RO_x + NO \rightarrow NO_2 + RO_y \tag{4}$$

$$2NO + O_2 \rightarrow 2NO_2 \tag{5}$$

$$RO_x + NO_2 \rightarrow RNO_3 \text{ (organic nitrates)} \tag{6}$$

where "M" in equation (3) represents an energy-accepting third body (such as a molecule or particle) and RO_x and RO_y are radicals that form only when organic reactants are present in the system.

In the absence of organic pollutants, the only reactions are those described by equations (1), (2), (3), and (5). Both reactions (4) and (5) represent the oxidation of NO to NO_2. Under any real atmospheric conditions, however, reaction (4) becomes dominant. The effects of the HC and NO_x reactants on ambient O_3 and NO_2 have been quantified by using smog chamber experiments, statistical/empirical analyses, and mathematical modeling methods (Dimitriades 1976). The following qualitative predictions about the relative roles played by HC and NO_x in oxidant and NO_2 formations may be inferred from reactions 1-6 and the smog chamber/mathematical modeling methods:

1. In urban atmospheres the HC to NO_x ratio is relatively low (5:1 to 20:1) owing to higher local emissions of NO_x. Reactions (2), (3), and (4) predominate, and the rate at which NO is converted to NO_2 (reaction 4) is controlled by the availability of organic compounds. Therefore, a combined strategy of controlling HC emissions from both mobile and stationary sources will tend to reduce the atmospheric concentration of oxidants in urban areas.
2. In rural areas where the HC to NO_x ratio is high and ranges typically from 30:1 to 100:1, reactions such as (6) compete with reaction (2) in removing NO_2 from the system. The atmospheric chemistry system becomes insensitive to increases in concentration of organic precursors, but is limited by the availability of NO_2. Therefore, the oxidant control strategy should be based on reducing NO_x emissions.
3. In cases of moderate ratios of HC to NO_x (20:1 to 30:1), such as in suburbs downwind from urban areas, the reactions between radicals and NO_2 begin to limit the NO_2 to NO ratio. The control of HC emissions in urban areas will allow more NO_x to escape the urban photooxidation process and be transported downwind, causing more oxidant formation in those areas. Control of NO_x emissions in the suburbs will tend to mitigate the formation of oxidant.

Carbon Monoxide Emissions

Mobile sources are responsible for about 85 to 90 percent of this pollutant in the ambient atmosphere (Bentz and Galvis 1975). However, while there is general agreement that carbon monoxide in all concentrations interferes with the oxygen-carrying capacity of the blood, the contribution of carbon monoxide to the environment from motor vehicle emissions has not been shown to be a significant factor affecting community health (U.S. DOT 1976). To the extent that a problem exists, preliminary studies show that it is localized at sites close to heavy traffic congestion and that it largely affects individuals spending many hours at such sites. However, research is under way on health effects of CO, and monitoring of human exposure to this pollutant is being refined. If the results indicate that the health risk is more severe than is currently expected, a review of the CO standard will then be in order.

An argument for adopting a stringent statutory standard for carbon monoxide is that once a catalytic converter is installed for the control of hydrocarbons, carbon monoxide will be oxidized along with the hydrocarbons at no additional cost. This overlooks the fact that, in the absence of a 100 percent efficient catalyst, while both hydrocarbons and carbon monoxide are the products of incomplete combustion, their origin within the engine is sufficiently different (see the discussion above) that a stringent standard for carbon monoxide may result in compromises in engine efficiency.

Carbon monoxide can also play a role in the reaction chain which leads to the conversion of nitric oxide to nitrogen dioxide, but hydroxyl-free radicals must be present. In principle, these reactions can arise from the photodissociation of water molecules as well as from hydrocarbons. However, the former process is sufficiently slow even at high humidity in strong sunlight to be second order in comparison with the effects of reactive hydrocarbons.

Sulfur Emissions

Before the advent of the catalytic converter, cars burned and emitted any sulfur contained in gasoline as sulfur dioxide, which oxidizes slowly in air to form sulfates. By the time the oxidation reaction was complete, the resulting small-sized sulfate particulates would be widely dispersed. An oxidizing catalyst however, leads to the conversion of sulfur dioxide to sulfur trioxide prior to its emission from the tailpipe. Since this form can interact with water vapor to produce a sulfuric acid mist, it has been a cause for concern at locations where vehicular traffic is heavy. For example, a recent estimate[5] is that cars will contribute 10 percent of the sulfate level in downtown Los Angeles in three years. The use of air pumps to improve the efficiency of oxidizing catalytic converters—a step the industry may increasingly be taking—may quadruple sulfate emissions from automobiles (industry estimate). Recent tests (U.S. EPA 1974e, 1976b, 1976c) simulating freeway conditions seem to show, however, that the emissions from a steady flow of such air-pump catalyst-equipped cars still account for only about one-quarter of the sulfates at ground level. Thus, this would seem to be a case where stationary source controls are also necessary and may be more effective than automobile controls. However, it should be noted that the effective use of a three-way catalyst where an air balance is maintained between oxidation (HC/CO) and reduction (NO_x) processes would avoid the formation of sulfate. The introduction of this type of catalytic converter (together with its associated electronic oxygen sensors) is also desirable from the viewpoint of improved mileage efficiency.

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[5] Cass Environmental Quality Laboratory, California Institute of Technology, private communication, 1976.

The question has also been asked whether elimination of sulfur at the refinery is a cost–effective way to control this pollutant. Studies of the refinery industry indicate that available low-sulfur crudes (better than 50 percent have negligible sulfur content) can provide for catalytic-equipped auto needs through 1979 (A.D. Little 1974, Sheppard et al. 1976). For this purpose, the low-sulfur oils should be employed by all refineries in the unleaded gasoline. Beyond this time, either some form of sulfur removal at the refinery would be required, or emission controls on the automobile will have to be imposed. Depending upon the residual level adopted, the capital cost for sulfur removal at the refinery will cost between $1.8 billion (A.D. Little 1974) and $3.9 billion (Sheppard et al. 1976) for 100 ppm, and $4.8 billion (A.D. Little 1974) and $12 billion (Sheppard et al. 1976) for 30 ppm residual sulfur.

Lead and Octane Rating

While the deleterious effects of lead ingestion upon human health have been studied for some time (CEQ 1976a), it was the advent of the catalytic converter with its susceptibility to lead poisoning that led to the federal requirement for unleaded gasoline at the pump. As hydrocarbon emission standards are tightened and older cars are scrapped, the use of such catalysts for the gasoline engine will probably become universal. If so, the question of allowable levels of lead in gasoline will become academic. This assumes that no lead-tolerant catalysts will be developed, but even if they are, the phasing out of lead additives will continue to be recommended for reasons of health.

Fortuitously, the reduced engine compression ratios employed to meet the oxides of nitrogen standard obviate the need for high-octane-number fuel. Thus, the 91 research octane number (RON) unleaded grade, which is relatively easy for refineries to produce by selective blending of refined components, is adequate for the new catalyst-equipped cars. (The estimated cost is less than 1¢/gal [NRC 1974b]; the price at the pump, however, is as much as 5¢/gal more than the regular leaded grade of the same octane. This results from oil company marketing practices of discounting leaded gasoline.) Modest increases in unleaded octane rating up to 93 RON can be provided by the oil industry with a capital investment estimated at about $1 billion (A.D. Little 1974). This estimate is, however, questioned by the industry as being too low (Sheppard et al. 1976). In addition, there is an energy penalty in the refining process which rises with octane number. In view of the improvement in mileage that a higher compression ratio engine using such fuel can provide, it may be worthwhile to make such a RON grade gasoline available, if catalytic methods of controlling oxides of nitrogen emissions are adopted. However, higher unleaded octane ratings of the type associated with today's premium grade (99 RON) gasoline would entail a capital cost of many billions of dollars and a significant energy penalty (A.D. Little 1974, Sheppard et al. 1976). It will be reasonable to phase out this RON grade gasoline as the high compression engines of pre-1970 vintage disappear.

SUMMARY

Auto emissions and control methods interact in complex and often mutually conflicting ways. Control of CO and hydrocarbons can lead to higher emissions of oxides of nitrogen and to increased sulfate pollution. Some primary pollutants combine to form more dangerous chemical compounds. Reactions take place in the atmosphere under varying meteorological and sunlight conditions, widely different concentrations and rates of formation. The proper means of controlling pollution must be determined in the context of the general uncertainty surrounding control of emissions from automobiles and other sources.

The most important environmental interactions of automobile emissions appear to involve reactive hydrocarbons and oxides of nitrogen, and their combinations that form photochemical oxidants. Information on the conversion and transport processes is inadequate, and further studies are urgently needed.

There are three means of controlling NO_2 and photochemical oxidants from automotive sources. They are: (1) stringent reduction of emissions of hydrocarbons, (2) stringent reduction of oxides of nitrogen, and (3) stringent reduction of both hydrocarbons and oxides of nitrogen. Smog-chamber, statistical/empirical and mathematical modeling methods indicate the following effects of each of the above control methods:

- It is established that HC controls will reduce urban oxidant levels, but will probably allow more urban NO_x to be transported to contaminate the suburbs and rural areas, with resulting increases there in oxidant levels.
- HC controls may provide some reduction in concentrations of NO_2 as a result of additional dilution allowed by the delay in completing the NO oxidation when lower HC levels are present.
- NO_x controls will reduce ambient NO_2 concentrations. The impact

on average annual levels of NO_2 will be more pronounced than on maximum hourly levels.

- It is hypothesized that the best strategy for controlling oxidants in rural areas (and to a lesser degree suburban areas) is a combination of controls of HC and NO_x emissions.

Carbon monoxide is not deemed a significant hazard to community health at today's emission levels. Although the cost of meeting a more stringent standard for carbon monoxide seems low, the added benefits to community health are questionable, and any resulting compromise with hydrocarbon elimination should be avoided.

Sulfates emissions from automobiles appear at present to be a relatively minor problem. In view of current—though incomplete—evidence that the contribution of cars to the ambient sulfate level is small, and in view of the availability of crudes that can be blended to provide low-sulfur content in unleaded gasoline for the next several years, no desulfurization has been required at the refinery, and a sulfate emission standard for cars has not been established. When capital investment alone is considered, the cost of equipping all power plants with sulfur dioxide scrubbers (about $4 billion) is on the same order as the refinery capital cost of eliminating sulfur from oil. Since coal-burning power plants are the major source of this pollutant, however, the former action would result in a far greater improvement in ambient air quality than would the latter. (The regional nature of the sulfate problem is discussed under Issue 4.)

Current reductions in the lead content of gasoline and its octane rating result from the demands of other pollution control measures (catalysts and lower compression ratios, respectively). Because control strategies are likely to continue to follow the current basic pattern, there appears to be no need for alteration of the current lead and octane measures.

CONCLUSIONS AND RECOMMENDATIONS

The Committee found several areas of concern in the current strategy of EPA—as mandated by Congress—for further tightening control on automobile emissions. Early efforts by Congress and EPA to control air pollution dealt with various pollutants on an individual basis without due consideration for their interrelationships. More recently, the Agency has begun to develop a better understanding of these relationships and to manage its programs accordingly. To best serve the public interest, this approach must be continued with even greater attention directed toward understanding the biological chemical and physical interaction of various air pollutant species.

Although the primary requirement of all air pollution strategies and standards must be the adequate protection of human health, the Agency should make sure that in meeting this criterion, it chooses those abatement strategies that minimize consumption of energy resources. With this concern in mind, the Agency should pay particular attention to the trade-off between stationary source and mobile source NO_x control. Further, enforcement of tighter NO_x controls on mobile sources should be managed in such a way as to permit future development and market testing of alternative engine designs, such as the diesel and stratified charge. Finally, new pollution abatement requirements on traditional engine designs should also try to minimize any additional fuel penalties.

The statutory standard should be imposed for hydrocarbons without the delay called for by pending legislation, but with due emphasis on stationary source controls, primarily in the area of gasoline marketing and solvent evaporation, and taking account of the reactivity of the specific hydrocarbons emitted.

The Committee also recommends that further reductions in carbon monoxide emissions should be subordinated to insuring flexibility in solving the cold-start hydrocarbon emission problem, and to improving gas mileage. This conclusion is based on present knowledge of health effects; new knowledge of the health risk of CO may, however, dictate stricter CO standards

The Committee recognizes that introducing controls only on new cars means that ambient air quality will improve slowly as older cars are retired. For this reason it may be desirable to retrofit cars now equipped with catalysts (the last two model years) with air pumps and cold storage or quick heat components as a means of accelerating air quality improvement in regions such as Los Angeles. There are obvious problems in the equitable distribution of these costs.

The Committee has been both impressed and concerned over the insufficiency of the research base that has been used in deriving the various and sometimes contradictory recommendations substantiating auto emissions control. It seems to the Committee, therefore, that the public and the automotive industry would be well-served by a systematic investigation of atmospheric reactions among various pollutants that are still insufficiently understood.

On the basis of present, albeit incomplete evidence, we recommend no auto sulfate emissions standard at this time. If the automotive contribution to the ground level sulfuate problem makes some form of control mandatory in the future, then an emission standard on cars is recommended as the primary strategy rather than desulfurization of gasoline at the refineries. We believe this may be the case by about 1980, unless the introduction of a three-way catalyst or alternative engines alleviate the problem sooner. In the meantime, refineries should use as far as possible the available low-sulfur crudes (less than 100 ppm) in blending unleaded gasoline.

The Committee endorses the current policy of eliminating lead from gasoline. The oil industry should not be required to provide a higher octane grade of unleaded gasoline until the directions taken by the auto industry to improve engine efficiency become clearer.

ISSUE 3
THERMAL WATER POLLUTION FROM ELECTRIC POWER PLANTS

STATUTORY STATUS

Heated water discharges were labeled pollutants in the FWPCA Amendments of 1972. Steam-electric power generation accounts for approximately 80 percent of total water used for industrial cooling (NCWQ 1975), and therefore contributes by far the largest amount of thermal water pollution. Steam-electric power was one of 27 industrial point sources specifically identified in the legislation.

The Act required effluent limitations reflecting "best practicable control technology currently available" (BPT) by July 1, 1977, and "best available technology economically achievable" (BAT) by July 1, 1983. However, the Act also provided for less stringent limitations if the owner or operator of a point source could demonstrate that its effects would be slight enough to assure "the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife" (Section 316).

The Administrator of EPA in 1974 established final effluent limitation guidelines (U.S. EPA 1974f) for steam-electric power generation. For BPT no additional restraint was imposed. The regulations for BAT, which were specified according to the age and size of the power plant, essentially limited new power plants to almost no discharge of heat to water bodies. In effect, this limitation requires closed-cycle evaporative cooling (cooling towers); however, EPA estimates that 70 percent of new power plants could avoid closed-cycle evaporative cooling (exemptions under Section 316).

Recently proposed amendments to the final effluent limitations guidelines (U.S. EPA 1976e) would allow heat discharge to on-stream "recirculating cooling water bodies."[6] The criteria for such water bodies are: (1) an environmental test requiring that both the construction and operation of the impoundment or water body be acceptable in terms of effects on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas; (2) a thermal efficiency test requiring that the discharge from the water body, on a long-term average annual basis, contain no more than 2 percent of the waste condenser heat passed to the cooling water body; and (3) a recirculation requirement establishing a flow restriction limiting the total discharges from the water body, on a long-term average annual basis, to no more than 100 $ft^3/sec/1000$ MWe generating capacity (nameplate capacity) of the facility. Because state water quality standards must still be achieved in the impoundment and adjacent stream reaches, some amendment of these standards may be required (U.S. EPA 1976e).

THE POSITION OF INDUSTRY

Representatives of companies that generate more than half of the nation's electricity have combined to challenge in court the EPA's final limitations guidelines of 1974 (*Appalachian Power Co. et al.* v. *Train* 1976). The major contention of the electric companies is that EPA regulations are too inflexible, resulting in enormous costs, wasted resources, and little, if any, environmental benefit. Specifically, the industry argues that guidelines should be applied only when necessary rather than in all cases; that a blanket requirement for retrofitting closed-cycle cooling systems is unjustified; that cooling systems on nuclear power plants that have been approved by the U.S. Atomic Energy Commission (AEC) under NEPA standards should not be changed by EPA regulations; and that prohibition of heated water discharges to cooling lakes is arbitrary and capricious (NCWQ 1975:124-125). The U.S. Court of Appeals for the Fourth Circuit held (July 16, 1976) that EPA in its reconsideration of its 1983 thermal retrofit regulations for steam-electric power stations must weigh costs and benefits in establishing that a particular level of effluent reduction is "economically achievable and reasonable" as required by the Federal Water Pollution Control Act.

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[6] The U.S. Court of Appeals for the Fourth Circuit (July 16, 1976) remanded to EPA for further consideration EPA's ban on the use of new and existing cooling lakes as an acceptable form of closed-cycle cooling.

THE POSITION OF EPA

EPA contends that its guidelines fulfill a legislative mandate for uniformity while retaining a sufficient degree of flexibility. The Agency argues that it has been fair to the industry while complying with the Agency's responsibility to act in an independent and unbiased manner. It rejects the industry's interpretation that standards accepted by other governmental bodies should be adopted by EPA. The Fourth Circuit Appeals Court also rejected this judgment.

The Agency has modified its original Development Document (U.S. EPA 1974a) as a result of comments received in a succession of briefings and hearings. The latest proposed amendments (U.S. EPA 1976e) to effluent guidelines incorporate several suggestions that have originated since the first publication in 1974. EPA asserts that its modifications have greatly reduced the costs and difficulties of compliance and that its latest standards are reasonable and effective.

DISCUSSION

Alterations in a water body's temperature by thermal discharges can effect three types of change: (1) physical, e.g., the reaeration rate; (2) chemical, e.g., rates of reaction between naturally present chemical constituents or those introduced by man's activities, or both; and (3) biological, e.g., out-migration or death of species with little resistance to changes or fluctuations in temperature. Changes of the first two types can also act to intensify the effects of thermal discharges in causing biological changes.

The primary test for determining whether a thermal discharge is environmentally safe is the assurance of the protection and propagation of a balanced, indigenous community of shellfish, fish, and wildlife in and on the body of water into which the discharge is made (see Section 316 of PL 92-500). Examples of nonassurance include: (1) death of a species induced by a sudden change in temperature, including the discharge of cold water after a plant shutdown; (2) forced emigration of a desirable species or the immigration of an undesired species; (3) disruption of temperature ranges favorable for breeding areas; and (4) creation of community instability by a change in the optimum temperature at which that community has developed (Rosen et al. 1974).

As may be inferred from the above discussion, the environmental effects of thermal discharges are site-specific. The effects also vary with geography and time of year. Depending on the site, thermal discharges may have detrimental, beneficial, or minimal effects.

Our knowledge of the effects of thermal discharges on biological communities is inadequate. In its Staff Draft Report, the National Commission on Water Quality stated:

> It is possible that in many instances detailed and extensive field studies accumulating a massive body of documented findings for each site will be necessary to support the need for closed-cycle cooling, and that review of extensive, detailed, site-specific information by regulatory agencies charged with final determinations will be a major undertaking (NCWQ 1975).[7]

Although it is impossible to reach an exact conclusion on the effects of thermal discharges, there appears generally to have been little detrimental effect to date. This is partly due to the small size and dispersed location of power plants in the past. However, as both size and concentration of power plants increase, significant environmental damage may occur in specific locations. Environmental constraints indicate that thermal pollution control strategy should be flexible so as to respond to site-specific conditions.

The costs associated with meeting proposed effluent guidelines involve the economic costs of building and operating closed-cycle evaporative cooling systems, the costs in energy required to operate these systems, and the environmental costs in adverse effects (e.g., air emissions, or impacts on the land) that may result from thermal control. (For more detailed discussion of this topic, see Working Paper II.)

Economic impacts of pollution control vary according to assumptions made about the degree of restriction, the number of exemptions, and the costs of the particular system. Several estimates are shown in Table 3.2. The data are derived from studies conducted during the evolution of final limitation guidelines, and consequently they are often based on different conditions. The data should not be directly compared: they are given only to illustrate the order of magnitude of expected compliance costs. Generally, cost estimates have decreased with time as EPA modifies its proposed standards and allows exemptions for plants in more favorable conditions, and as suppliers bring in cheaper and more reliable pollution control equipment.

Energy requirements associated with meeting thermal standards are of two kinds: energy consumed to construct, operate, and maintain the control system (including the energy embodied in the materials of construction), and less efficient use of energy in operation of the steam turbine. While the amount of energy used to run the pumps and fans of a

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[7] On September 5, 1968 the USGS requested its Regional Hydrologists and District Chiefs of the Water Research Division to provide them with lists of rivers where the temperature rise was 70°F or greater. None was found in the United States.

TABLE 3.2 Estimates of Economic Impact of Thermal Pollution from Power Plants by 1983

Date	Source	Estimated Total Capital Costs ($ billion)	Comments
March 1974	Development Document (U.S. EPA 1974a)	12.0	Considers estimated effect of exemptions
March 1974	Economic Analysis (U.S. EPA 1974b)	14.5	
June 1974	Edison Electric *et al.* (1974)	28.0	
October 1974	Bureau of National Affairs (1974)	25.0	EPA estimate, 50% exemptions.
October 1974	U.S. EPA (1974f)	5.2	Before exemptions considered
		2.7	After exemptions considered
January 1976	EPA Draft Report (U.S. EPA 1976d)	1.7	To meet combined standards

cooling tower system is small relative to total unit capacity, energy losses due to lowered operating efficiency are significant (U.S. EPA 1974a).

A steam-electric power plant is a heat engine that depends upon the temperature difference between a heat source (boiler steam) and a heat sink (the condenser) for its operating efficiency. As the temperature difference between source and sink decreases, operating efficiency also decreases. An evaporative cooling tower decreases the temperature difference by causing the condenser to operate at higher temperatures, thus lowering the efficiency of the steam-electric turbine. Energy penalties associated with closed-cycle evaporative cooling range as high as 12 percent, though the usual penalty is from 2 to 6 percent (U.S. EPA 1974a).

In addition to the economic impacts and energy requirements involved in building and operating cooling towers, there are environmental effects that must be considered. The thermal plumes from cooling towers interact with the ambient atmosphere to increase humidity and raise the air temperature. These changes may in turn lead to higher average precipitation, fog, ice, or turbulence (Huff et al. 1971, Bartels and Casper 1975). If brackish or saline water is used for cooling, the productivity of surrounding land areas may suffer from contamination by drifting salts (Pell 1975). The noise and height of tall cooling towers are aesthetically displeasing to some observers. These negative effects are difficult to quantify, but they should, somehow, be weighed against benefits to be expected from thermal pollution control.

CONCLUSIONS AND RECOMMENDATIONS

Regulation of thermal pollution is preventive rather than remedial in intention. Immediate environmental benefits expected from the regulations are generally negligible, while the energy and economic penalties are significant. (The energy penalty for closed-cycle evaporative cooling is commonly 2 to 6 percent.) Without regulation, however, adverse impacts are to be expected in the future as more and more electric power plants line the nation's rivers and lakes.

The Committee agrees with the preventive approach to environmental planning (see Chapter 4). It believes that the management structure for establishing thermal pollution control policy lends itself to flexible and effective protection of the environment. It recommends that the basic structure and approach be retained.

Some problems need to be solved before the strategy can be effective. In the development of guidelines for thermal pollution control, not enough emphasis has been been given to determining the impact of proposed regulations. Important comparisons among environmental benefits and economic expenses, energy requirements, and environmental costs for different time periods have been neglected.

We conclude that closed-cycle cooling is not currently cost–effective in most instances, either in energy or in dollars. We recommend, therefore, that closed-cycle cooling not be required now where the effects of thermal pollution on ambient conditions, fish, and wildlife are still negligible, but only where and when it is necessary to prevent significant harm to the environment. Although the burden of proof in such instances should properly rest with the power plant involved, EPA should adopt a selective and sensitive pollution control policy adaptable to the variable and changing circumstances characteristic of the thermal discharge issue.

In short, the Committee urges the application of pollution control policy that can recognize and adapt to the variable and changing circumstances characteristic of the thermal discharge issue. It should be noted that, in the long run (beyond the time period covered by this report) the overall heat output must be limited because of adverse global climatic effects.

ISSUE 4
CONTROL OF SULFUR DIOXIDE EMISSIONS FROM ELECTRIC POWER PLANTS

STATUTORY STATUS

The sulfur dioxide ambient air quality standard is aimed to protect human health. It is mandated by the Clean Air Amendments of 1970 (42 USC 1857 et seq. 1970; PL 91-604). EPA established a primary standard of 80 $\mu g/m^3$ annual arithmetic mean, with the maximum 24-hour standard not to exceed 365 $\mu g/m^3$ more than once yearly (U.S. DHEW 1970). Each state is required to limit emissions from stationary sources to meet these national ambient standards (CEQ 1976a).

The states submitted their implementation plans in 1972. In almost all cases, the emission limitations with which utilities were required to comply called for a strategy of continuous source reduction of SO_2 emissions, such as by switching to low- or medium-sulfur fuels, washing or blending effluents, or installing continuous sulfur dioxide removal devices (i.e., scrubbers). EPA subsequently required continuous (as opposed to intermittent) sulfur dioxide emission limits for all power plants. The deadline for compliance was mid-1975, but much of the electric utility industry did not meet the regulations on time.

Court appeals on the requirement for continuous sulfur dioxide emission controls have lasted for years. After a long series of extended litigations, the U.S. Supreme Court in early 1976 refused to review an appeal to a U.S. Circuit Court ruling that upheld EPA's interpretation for continuous control. Thus, barring a new act of Congress, the EPA regulatory policy will stand.

THE POSITION OF EPA

In 1972 EPA recognized the fact that the available supply of low-sulfur fuel and scrubbers was not sufficient to achieve compliance with state emission limitations by the 1975 deadline. It therefore instituted a Clean Fuels Policy which (1) encouraged coal-consuming states to revise regulations where public health would not be endangered, and (2) allowed compliance schedules to be written which extended beyond the 1975 statutory deadline.

EPA maintains that this policy conforms with the provisions of the Clean Air Act, but that intermittent control systems do not. It feels that the so-called intermittent control systems (ICS), which reduce the rate of sulfur dioxide emissions only when meteorological conditions might cause high ground-level concentrations (Montgomery et al. 1975) do not adequately protect public health.

EPA policy does, however, allow the use of tall stacks and/or ICS as a temporary measure to meet air quality standards in limited instances where the installation of necessary emission control technology might be economically unreasonable or technically infeasible (U.S. EPA 1976h). In these circumstances, EPA requires the plant to install reasonably available (as opposed to "best available" or "maximum achievable") constant controls. Since reasonably available control technology (RACT) is based upon economic and engineering considerations, the acceptability of different control techniques would be determined on a case-by-case basis, including consideration of plant age and utilization.

THE POSITION OF INDUSTRY

Members of the electric utility industry proposed the intermittent control system as an alternative to continuous control of sulfur dioxide emission. The technical basis for intermittent control systems is empirical evidence that variations in meteorological conditions result in significant changes in the air quality implications of any given level of emissions. Thus, the industry contended that routine operational adjustments (fuel switching, load redistribution, changes in stack gas temperature) by utilities in response to atmospheric conditions could satisfactorily assure good ambient air quality.

Representatives of electric utilities have also argued that continuous systems are neither reliable nor readily available. They point to operational failures of scrubbers as proof of unreliability. They claim that the sulfur dioxide problem is "minuscule" since less than 1 percent of the concentrations reported from 1969 to 1975 exceeded the primary ambient level. They also claim that intermittent control systems for SO_x are much more cost–effective than continuous control systems which are wasteful of resources and energy.

As part of their position on the merits of intermittent versus continuous control systems in general, utility spokesmen emphasize the effects that continuous systems might have on marginal units. They warn that the costs of control will far outweigh environmental benefits. Older, smaller units contribute only a small portion of total sulfur dioxide emissions, yet they will require the same control system as larger, newer units. The added capital and operating expenses may make use of these older plants uneconomical; and if they are closed, a further waste of resources will be brought about, it is asserted, by the new capacity required to replace them. (See Working Paper III for full discussion of this topic.)

THE POSITION OF ENVIRONMENTAL ORGANIZATIONS

Environmental groups consider intermittent controls unsatisfactory, because tall stacks lead to dispersion rather than to control of pollutants. They point to new evidence that indicates that tall stacks increase the amount of SO_2 conversion to sulfates and sulfuric acid by increasing the time pollutants remain suspended in the air. Furthermore, sufficient data are available on long-distance transport of SO_x and its products to show that tall stacks may reduce SO_x concentration near the plant but increase it farther away.

DISCUSSION

There is no disagreement about the need to control sulfur dioxide emissions for the protection of human health and the environment. The extensive literature available in this area, and the description in Chapter 2 of the effects of sulfur dioxide and the resultant formation of sulfates make clear the consequences of permitting uncontrolled sulfur dioxide emissions from electric power plants. Similar descriptions have convinced both industry and government that there is a basic need for control. The controversy has been over *how*, not *whether*, sulfur should be limited in the atmosphere.

This discussion will briefly compare two control strategies: flue gas desulfurization (FGD) and fuel switching. Flue gas desulfurization is a continuous control process which, with the current state of technology, is best represented by a limestone-slurry stack gas scrubbing system. Fuel switching is an intermittent control system. These two examples offer a good comparison in terms of data quality, operating experience, and most likely application (NRC 1975a: Chapters 11 and 12, Devitt et al. 1976, Gaut and Schweppe 1975).

The flue gas desulfurization system is normally designed to remove 80 to 90 percent of the sulfur dioxide from stack gas (see Working Paper III). Accordingly, a power plant with flue gas desulfurization gives off between one-tenth and one-fifth of the sulfur dioxide it would emit with no control. In contrast, a plant using fuel switching gives off a much higher fraction of the sulfur dioxide it would emit with no controls, since it only limits sulfur dioxide during short periods of adverse meteorological conditions. Both systems, however, may meet local air quality standards.

Although local conditions may be acceptable, total sulfur dioxide emissions seem to present a better criterion for judging the overall performance of the system. A variety of considerations has been offered to justify continuous emission controls; chief among them is the issue of long-distance transport of sulfur oxides emitted from large stationary point sources. While conclusive evidence for long-distance transport is lacking, circumstantial evidence is quite compelling. Broad areas of the United States in which fossil fuel electric power plants are concentrated have the highest region-wide concentrations of suspended sulfates. This measure is an index, albeit quite crude, of the transformation products of sulfur dioxide emissions. Rural as well as urban levels of sulfates throughout much of the northeastern United States are two to five times higher than levels in the less populated areas of the West. Geographical differences in the acidity of rainfall also support the argument that atmospheric loading with sulfur dioxide from point sources results in widespread regional dispersion of acid-producing sulfur oxide transformation products (see Chapter 2).

The impact of sulfates on health is widespread as well as local, because the atmospheric conversion of sulfur dioxide to sulfates may take from a few hours to a few days. Therefore an intermittent control system strategy tied to local (and short-time) measurements of sulfur dioxide levels does not completely address the problem of protecting environmental quality from the impacts of sulfates. Rather, the total sulfur dioxide emitted by all sources contributing to regional pollution would have to be reduced to reduce regional sulfate concentrations and thus avoid harm to health and the environment.

Similarly, the use of tall stacks to reduce the concentration of sulfur dioxide at local ground stations may have adverse effects on regional air quality. The upper levels of the atmosphere reached by emissions from such stacks contain higher concentrations of the oxidizing components that facilitate rapid conversion of sulfur dioxide emissions into sulfates. Thus, higher levels of sulfates may be reached downwind of the plant site than would otherwise be the case.

The economic costs and energy requirements of fitting existing power plants with flue gas desulfurization and with intermittent control systems have been estimated in work done for the Committee by Hittman Associates (Working Paper III). These findings (corrected on the basis of a 4-6 percent energy penalty [Hollinden et al. 1976]) are presented as estimates of the impacts associated with sulfur dioxide control (see Table 3.3). At present, the difference between requiring all plants to adopt flue gas desulfurization and permitting maximum possible use of intermittent control systems is:

$3 billion in capital costs
$1 billion per year operating costs
50-75 trillion kilocalories (195-295 trillion BTU) per year fuel penalties (approximately 8-12 million tons of coal).

TABLE 3.3 Control Systems Costs and Energy Requirements

	Limestone FGD	Fuel Switching ICS
Capital Cost ($/kw)	79.40	5.16
Operating Cost (mills/kwh)	3.61	0.09
Fuel Penalty (%)	4.0-6.0	0.0

CONCLUSIONS AND RECOMMENDATIONS

The interpretation of the 1970 amendments to the Clean Air Act raised a controversy over which strategy to adopt to attain the specified ambient air standards. In spite of several court decisions to the contrary, the electric utility industry argues that continuous source reduction for sulfur dioxide emissions is unnecessary and too expensive. The utilities question why they must reduce their emissions to low levels all the time even though local ambient air quality levels exceed the standards only intermittently, and very seldom at that. They would like, in certain circumstances, to abate to a lesser degree of control, using tall stacks to disperse the pollutants more widely and reduce their ambient concentrations, while adopting supplementary controls such as production cutbacks and a switch to low- or medium-sulfur fuels during bad air quality conditions.

Decisions on the best means of controlling sulfur dioxide emissions from power plants require a balancing of imprecisely known risks to health and the environment against large expenditures of energy and other economic resources. There is room for a variety of opinions on the proper balance between these factors. While the dangers of sulfur dioxide emissions have been established in general (see Chapter 2), there is no satisfactory means of quantifying them in the particular case of transported and transformed pollutants. The Committee itself includes members with differing points of view.

Nonetheless, the preponderance of opinion in the Committee is that there are long-distance and time-delayed reactions of sulfur dioxide in the atmosphere. Since the sulfate problem is probably widespread rather than local (due to long-distance transport) and delayed rather than immediate, a site-and-time-specific approach such as intermittent control systems may not address the problem adequately. Furthermore, because of likely regional effects, variances for power plants in rural areas are questionable, but waivers for old, low-load plants are acceptable. The consensus of the Committee, then, is that although the costs of control are high at present ($1 billion per year operating costs and 33 to 49 million barrels of oil per year energy expenditure), the risks to human health are sufficiently great to warrant continuous rather than intermittent controls as the basic approach to sulfur dioxide control. The difficulty of developing a basis for exceptions related to region and time leads to our judgment that a nearly uniform administration of the continuous control strategy should be used (but see the discussion in Chapter 4 of uniform versus nonuniform approaches). We choose this administratively conservative posture understanding that it is controversial.

The Committee suggests, however, a modification of the current regulations in accordance with the EPA policy of reasonably available control technology. While we reject the variance approach, it does seem reasonable to include a waiver of the requirement for a continuous system for old power plants that: (1) operate at a low-load factor, or (2) contribute only a small proportion of the ambient sulfur dioxide concentration. The exact age and emission fractions should be set after further study. Under all circumstances, however, national ambient standards should be met. The exceptions we envisage would, stringently observed, neither alter the basic EPA approach nor incur lengthy court delays. In addition, they would place no unnecessary burdens on electric utilities.

While there was diversity of opinion in the Committee over the desirability of particular control technologies and when they would be ready for use, the members concurred that new technology, such as fluidized bed combustion, should be encouraged, for it will meet the multiple objectives of continuous control without additional energy costs.

ISSUE 5

"AS LOW AS PRACTICABLE" RADIOACTIVE EMISSIONS

STATUTORY STATUS

The issue of control of radioactive emissions from nuclear power plants involves a confused set of recommendations, guidelines, and regulations. (See Working Paper IV for detailed discussion.) Several federal agencies have had, and still exercise, control over nuclear materials and processes at some point in the fuel cycle. Two advisory bodies, the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP), have both held that radiation exposure should be "as low as practicable" (ALAP) (now renamed "as low as reasonably achievable" [ALARA]), and that no exposure should be allowed without some concomitant benefit (ICRP 1966, NCRP 1971). These recommendations were followed by the Federal Radiation Council (FRC 1960, 1961). The Atomic Energy Commission adopted them on December 3, 1970, when amendments to an AEC regulation were published requiring that effluents from light water power reactors to unrestricted areas be "as low as practicable" (U.S. Nuclear Regulatory Commission [NRC] 1975). However, the amendments did not set numerical limits.

On June 9, 1971, AEC published its proposed regulations for exposure to ionizing radiation of members of the public near a reactor (U.S. AEC 1971a): (1) whole-body and skin dose to an individual off site was not to exceed 5 mrem/year from gaseous effluents, and the dose to the thyroid or any organ was not to exceed 5 mrem/year from radioactive iodine and particulates; (2) annual average site-boundary or offsite concentrations of radioactive iodine or of particulates with half-lives greater than eight days were not to exceed 1/100,000 of the allowed concentrations to occupational workers in air set by federal standards; and (3) total annual liquid effluents except tritium were not to exceed 5 Ci, nor was the concentration to exceed 20 pCi/l. Tritium release concentrations were not to exceed 5000 pCi/l.

Public hearings began in January 1972, but they were suspended for publication of an environmental impact statement. Finally, the hearings concluded in December 1973, after thousands of pages of transcript were produced.

The U.S. Nuclear Regulatory Commission (successor to the regulatory and enforcement arms of AEC) published ALAP regulations on May 5, 1975 (U.S. NRC 1975). The regulations removed specified numerical limits for quantities of radioactive materials in liquid effluents. Instead, they set design objectives for each reactor on a site such that the annual doses, or dose commitments, are limited. Any person in an unrestricted area should receive no more than 3 mrem/year exposure to the total body and 10 mrem/year to any organ from the liquid effluents of a nuclear reactor. Exposure from gaseous effluents (each reactor/year) should not exceed 5 mrem/year to the total body and 15 mrem/year to the skin, nor should exposure from radioactive iodine or particulates to any organ exceed 15 mrem/year. Probably the most controversial aspect of the ALAP regulations was the requirement that cost–benefit analysis be used to determine whether or not additional radiation-waste treatment is necessary. The regulations require that "purely as an interim measure" up to $1000 be spent for each person-rem reduction in radiation dose to the general population within 50 miles of a reactor site (U.S. NRC 1975). (For more detailed information see Working Paper IV.)

These limits for radiation dosages at the perimeter and in the vicinity of light water reactors do not abrogate the nonoccupational standards set by the Federal Radiation Council (NCRP 1971, U.S. AEC 1971b), which, while complicated, can be summarized as 500 mrem/year whole-body average dose per individual and 170 mrem/year whole-body average dose for the population at large.

Further complicating the issue is the fact that the Federal Radiation Council was dissolved and its function assigned to EPA. On May 29, 1975, EPA proposed annual radiation protection standards for any member of the public from the entire uranium fuel cycle (U.S. EPA 1975b). For each gigawatt-year of electrical energy, the following restrictions would apply to radiation exposure from planned releases (radon and its decay products excepted): (1) no more than 25 mrem-whole body, 75 mrem-thyroid, and 25 mrem to any other organ; and (2) less than 50,000 Ci of ^{85}Krypton, 5 Ci of ^{129}Iodine, and 0.5 mCi of ^{239}Plutonium and other alpha-emitting transuranics with half-lives greater than one year.

THE POSITION OF INDUSTRY

Representatives of the nuclear power industry assert that the "as low as practicable" concept is not properly translated into action by current regulations, and they point to several factors they believe are inconsistent with "practicable" standards. The reductions to be attained are small compared to other sources of man-made radiation, particularly radiation from medical X rays. Industry spokesmen contend that it is unreasonable to limit radiation from the nuclear fuel cycle stringently while little attention is devoted to other sources.

The industry argues that costs associated with the Nuclear Regulatory Commission standards are higher than can be justified. They especially think that $1000/person-rem reduction places a higher value on health effects than is generally accepted. Furthermore, reductions in exposure of the general population may necessitate increased handling and manipulation of radioactive waste that would lead to higher exposure for the in-plant work force and perhaps, to an even higher overall exposure of the whole U.S. population as measured in person-rem. Where a cost–benefit analysis (given the $1000/person-rem figure) might indicate that improved waste treatment was worth undertaking, considerations of cost–effectiveness taking into account all other sources of exposure of the population to radiation would demonstrate that other steps could be more cost–effective.

DISCUSSION

In February 1970, AEC asked the National Academy of Sciences–National Research Council to conduct a complete review and reevaluation of existing knowledge concerning exposure of human populations to radiation. This request led to the issuance of *Biological Effects of Ionizing Radiation* (the BEIR report: [NRC 1972]), a study of the effects of low-level radiation on populations. This report serves as the basis for much of the assessment of risks from ionizing radiation. Two highly regarded documents in the field of radiation protection written before the BEIR report are Report No. 9 of the International Commission on Radiological Protection (ICRP 1966) and *Basic Radiation Protection Criteria* published by the National Council on Radiation Protection and Measurements (NCRP 1971). Both documents take the position that there is no absolutely safe dose of radiation and that all exposures should be reduced to the minimum exposure practicable.

There is general agreement that we do not at present have the ability to verify effects on health from nuclear fuel cycle emissions. For example, a study by EPA (1973) estimated that the average individual in the United States in the year 2000 (1000 reactors) would be exposed to 0.05 mrem/year of whole body radiation. Using BEIR estimates, the individual's "extra" risk of fatal cancer is about 1 out of 10 million (NRC 1972). The current fatal cancer risk is 17,500 out of 10 million from all causes (National Center for Health Statistics 1976). Thus, there is no way to determine in practice whether radiation-induced or "extra" cancers will occur at these low radiation levels.

The risk reduction from compliance with ALAP standards may be excessive compared to that called for in other social activities. Terrill (1972) estimated that every dollar spent on improved X-ray equipment would accomplish 1000 to 6000 times (250 to 1500 times based on an improved dosimetric model by the U.S. Public Health Service)[8] as much exposure reduction as the same dollar spent on reactor radioactive waste treatment systems. Radiation encountered during medical treatment continues to be the largest source of man-made radiation to which the U.S. population is exposed. The average individual receives 1000 times as much radiation from diagnostic medical X rays as from nuclear radiation (Klement et al. 1972).[9] Some critics of the ALAP standards maintain that the emphasis in radiation protection standards on a hypothetical individual at the boundary of a nuclear facility is inconsistent with other provisions for protection of the public from technological activities in our society (Hull 1972).

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[8] Terrill's analysis had to be corrected because the original medical dose was overestimated by approximately a factor of 4. 1964, 16 ± 6 MRAD; 1970, 20 ± 3 MRAD (U.S. PHS 1975).

[9] See note 8 above.

Models are widely used to estimate radiation doses from reactor effluents rather than actual measurement. The models use factors of safety that probably lead to higher estimates than might have been expected from measurements (Kahn et al. 1970, 1971). Most documents in which radiation dose estimates are given are conservative. No assessor of radiation dose wants to be accused of underestimating. The final Environmental Impact Statement on the ALAP standards (U.S. AEC 1973) estimated dosages where the AEC appeared to use conservatism in models of both environmental transport and dosage.

The purpose of reducing human radiation exposures is to reduce ill-effects on the health of exposed populations.[10] The regulatory requirement to spend up to $1000 to reduce a person-rem can be translated into effects on health of individuals and their progeny. If an upper estimate of 200 health effects per million rem/year (NRC 1972) is used, then $1000/person-rem implies expenditures of $5 million to avoid one health effect. This is a higher expenditure than many would suggest is reasonable. Of course, these analyses are dependent upon costs attributed to the value of a human life. Sagan (1972) used a value of $300,000 per life in analyzing certain human costs of nuclear power. This value translates to $30 per person-rem or $150,000 per health effect.

Table 3.4 gives the annual cost of averting health effects if facilities in the uranium fuel cycle meet the Nuclear Regulatory Commission ALAP criteria. Some facilities could meet ALAP limits under current practice, so no estimates are given for them. The cost per health effect for requiring reactors to meet ALAP limits is given, however. Some of these estimated expenditures exceed the $1000/person-rem ($5 million per health effect) limit. Ranges are given for the health effects and costs for reactors and uranium mills. They reflect population dose differences due to siting. Health effects estimated for reprocessing facilities include global health effects. Of the total annual health effects from the model reprocessing facilities, 0.8 percent occur in a 50-mile radius, 17.7 percent in the United States, and the remaining 81.5 percent in the world population.

Annual costs to meet ALAP requirements are high, but they do not represent a large proportion of total costs. Additional capital costs for a 2400 megawatt boiling water reactor are approximately $1.5 million; this

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[10] U.S. EPA October 1973 Environmental Analysis of the Uranium Fuel Cycle. Part I - Fuel Supply. Health effects per 10^6 rem aggregate dose include 50 mortalities due to lung cancer, 16 mortalities and 16 nonfatal cancers due to cancer of the skeleton, 54 mortalities due to leukemia, and 150 mortalities, 150 nonfatal cancers, and 300 genetic effects due to dose cell soft tissues and all organs other than the bone.

TABLE 3.4 Estimated Annual Cost per Health Effect Averted in Fuel Cycle Facilities Meet the Nuclear Regulatory Commission ALAP Criteria

	Total Health Effects per Year of Operation[1]		Annual Cost per Averted Health Effect ($\$10^6$)
	Current Effluent Control	ALAP	
Uranium mill	0.1	0.002	4.0-10.9[4]
Conversion			
Wet solvent	0.4	0.03	0.001[1]
Hydrofluor[2]	0.2	same	
Enrichment[2]	0.1	same	unknown
Fabrication[2]	0.1	same	
Reactors[2]			
BWR	0.007 -0.02	same	0.5-1.9[5]
PWR	0.0003-0.01	same	1.2-19.8[5]
Reprocessing[3]			
H-3	2.7	0.03	0.37[6]
Kr-85	6.7	0.07	0.21
C-14	12.0	0.12	0.12
Iodines	0.009	0.0009	33.8
Actinides	0.01	0.001	33.6

[1] U.S. EPA (1973).
[2] Currently meet ALAP at boundary.
[3] Reducing iodines and either H-3, Kr-85 or C-14 necessary to meet ALAP at boundary.
[4] Costs from Sears et al. (1975).
[5] Costs to make Case 1 ("dirty") reactors meet ALAP (U.S. AEC 1973).
[6] Costs from Finney et al. (1975).

adds a small cost of less than 0.2 mill per KWh (an addition of approximately 1 percent) (see Working Paper IV). Corresponding costs for pressurized water reactors are about half as much (see Working Paper IV). It can be argued that this is a small price to pay to allay doubt and secure public confidence. It does seem clear that the technology needed to keep individual doses to as low as practicable levels has existed and has been used in most nuclear power plants built during the past few years. However, the provision to augment further ($1000/person-rem) radioactive waste treatment systems to reduce population doses will doubtless continue to be a bone of contention between reactor operators and the Nuclear Regulatory Commission.

The energy requirements to meet ALAP standards consist of energy used to construct, operate, and maintain treatment devices including the energy embodied in the materials of control systems. Because the amounts of radioactive materials handled are small and because control systems enjoy long lifetimes, both categories appear to be negligible. Although retrofit of existing units may cause brief disruption of reactor operation, the one-time energy penalty associated with an interruption is expected to prove insignificant. Therefore, only small energy penalties are likely to be associated with installing and operating ALAP systems.

Technical difficulties associated with meeting ALAP limits may in fact lead to greater environmental impacts. To meet the requirements, it may be necessary to shut down reactors more frequently than would otherwise be required. Start-up and shut-down of reactors tend to be more hazardous than routine operation.

The question of practicable limits thus becomes a balance of one set of risks versus another, as well as of cost versus risk. Because risks from low level radiation are hard to quantify, and because risks of system failure may prove even more difficult to evaluate, it is unclear how risks should be weighed. There appears to be greater assurance that risks in start-up and shut-down can be reduced than that health effects will disappear, but safety always has finite limits. This start-up/shut-down problem, and increased occupational dose do not seem to have been given adequate attention during the formative stages of the ALAP regulations.

CONCLUSIONS AND RECOMMENDATIONS

The issue of achieving "as low as practicable" (ALAP) radioactive emissions from nuclear power plants presents an example of management difficulties characteristic of many environmental questions. We find that the health benefits to be expected from ALAP controls are probably small. On the other hand, costs are relatively low. Uncertainty as to exactly how small the health risks are, or unwillingness to assign a monetary value to human life or health, further complicate our attempts to determine a valid meaning for the word "practicable." The Committee nevertheless concluded that, in light of the great sensitivity of the public to radiation risks and the low relative cost of the regulations, the avoidance of the risk is worth the cost.

Study of this issue has, however, brought to light several deficiencies in current regulations on radioactive emissions. First, the regulations are unnecessarily fragmented because of overlaps among regulatory agencies. Some overlap of responsibility may be unavoidable, but regulations should still be better coordinated so as to be reasonably consistent and free of confusing duplications.

Second, cost–effectiveness of ALAP regulations has not been sufficiently pursued. The public undergoes far greater exposure from medical radiation than from nuclear reactor emissions, and equivalent reductions in radiation exposure from medical sources could be made at lower cost than that demanded by ALAP limits. More effort should be given to the cost–effectiveness of regulatory restrictions, so that the greatest benefits can be produced at the least cost.

Third, operational difficulties imposed by ALAP regulations may expose plant employees and the public to greater risks from accidents during start-up and shut-down of the reactor than would accrue from less disrupted operation at slightly higher emissions. Certainly it should be determined whether restrictive actions such as those directed by ALAP limits could involve risks as high as or higher than the other risks it is designed to reduce.

In summary, the Committee finds that the costs and energy requirements of ALAP regulations are acceptably small. It recommends, however, that a review of the ALAP standards should take place which will give more attention to coordination among agencies and to the trade-offs involved between cost–effectiveness and increased risks from disrupted operations to meet ALAP regulations.

ISSUE 6

SURFACE MINING OF COAL AND THE NATIONAL ENVIRONMENTAL POLICY ACT

STATUTORY STATUS

A broad array of environmental, health, and social problems is associated with the mining and processing of coal, for which a correspondingly broad array of legislation aimed at amelioration and prevention has been produced. Portions of this legislation relevant to our discussion are summarized in Table 3.5.

The Coal Mine Health and Safety Act of 1969 (PL 91-173) administered by the Mine Enforcement and Safety Administration (MESA) has had its major impact on underground mining, and has been credited with aiding the shift to surface mining. Mine operators, especially small mine owners, have argued that the costs associated with meeting MESA regulations place them at a competitive disadvantage. However, the increasing price of coal should compensate for the costs of meeting MESA requirements, particularly if improvements can be made in labor/management relations. Recent accidents have demonstrated the need for enforcement of the MESA regulations, and for increasing the fines imposed for violations that may result in accidents. Overall, there have been measurable decreases in electrical and haulage accidents after implementation of the Coal Mine Health and Safety Act, and production losses from fires and explosions have decreased by a factor of about six in

TABLE 3.5 Federal Environmental Laws and Regulations Affecting Coal Mining

Law or Regulation	Administrative Agency	Description	Permit or Approval Required	Remarks
Federal Water Pollution Control Act Amendments of 1972 (33 USC § 1251 et seq. Supp. 1975, PL 92-500)	EPA	Effluent limitations and National Pollutant Discharge Elimination System (NPDES)	Yes	
	Corps of Engineers	Section 404: restriction on placement of dredged or fill material in navigable streams and wetlands	Yes	
Federal Coal Mine Health and Safety Act of 1969 (30 USC § 801 et seq. 1970)	Mining Enforcement and Safety Administration	Environmental protection and safety of workers	Yes	
Mineral Leasing Act (1920) and Mineral Leasing Act for Acquired Lands (1947) Dept. of the Interior 43 CFR 3041 (1976)	Bureau of Land Management	Environmental analysis and protection required for surface management—federal coal	Lease terms	

Dept. of the Interior 30 CFR 211 (1976)	U.S. Geological Survey	Environmental analysis and protection required for mining operations–federal coal	Yes	Applies to existing and future mines
Dept. of the Interior 43 CFR 3500 (1976)	Bureau of Land Management	Environmental analysis and protection required before converting Prospecting Permits to Preference Right Leases–federal coal	Lease terms	Requires applicant demonstrate "commercial quantities" under new definition
	Bureau of Land Management	Energy Minerals Activity Recommendation System (EMARS); leasing on planned basis including environmental protection and competitive lease sales–federal coal	Lease terms	Approximately 4 years to implement; a substantial amount of public input; Environmental Impact Statement; Incorporates 43 CFR 3041 and 30 CFR 211
Mineral Leasing Act Amendments of 1976 S-391	Bureau of Land Management and U.S. Geological Survey	Provides for federal coal exploration program, environmental protection, increased royalties, higher percent royalty to states, production of coal in 10 years, increased public and state participation, competitive lease sales, no prospecting permits	Lease terms and mining approval	Supercedes portions of new Department of the Interior regulations and increases environmental safeguards; applies to federal coal; affects adjoining nonfederal coal

NOTE: The above listing does not include all federal environmental laws or regulations affecting coal mining, but summarizes the major ones. Other laws, such as special land-use regulations, also exist. All of the laws and regulations contain enforcement authority and penalties. In addition, states, counties, and municipalities have laws and regulations requiring numerous additional permitting, compliance, and enforcement actions.

comparison to a period of similar length shortly before the Act was passed.[11] Fatalities per 10^6 man-hours of deep mining have in recent years dropped to a level characteristic for strip mining (U.S. DOI 1975a).

The FWPCA Amendments of 1972 affect coal mining in two ways: through authorization of the National Pollutant Discharge Elimination System (NPDES), administered by EPA; and through the dredge-and-fill permit requirements, or "404 Program," administered by the Corps of Engineers.

Although the NPDES was authorized in 1972, EPA has been slow in applying it to the coal industry, instead concentrating its initial efforts on industries that were more clearly "point sources" of pollution. Before mid-1976, some permits were issued in accordance with EPA's interim effluent guidelines, which set limits for pH only. EPA has recently published more complete effluent limits for water discharges from both surface and underground coal mines, as well as for preparation plants (40 CFR 434, 1976). Limitations are set for pH, suspended solids, total iron, dissolved iron, acidity, alkalinity, and manganese in the mine discharge.

The Corps of Engineers, authorized by Section 404 of the FWPCA Amendments, has promulgated regulations concerning placement of dredge and fill material in navigable streams or their tributaries. This regulation can affect surface mining, which frequently involves diversion of small streams or their disturbance through soil slippage or sedimentation. To date, however, the 404 Program has been only partially implemented with regard to coal mining. So far, only Phase I, which affects tidal waters and waters involved in interstate or international commerce, is in existence. Phases II and III (pertaining to progressively smaller and more upstream waters), which are more likely than Phase I to affect coal mining activities, have, as a result of strong pressures by developers and some farm interests, been temporarily halted by administrative directive and may be altered by Congressional action.

A related major issue is the mining of coal on public land, particularly western land. (For full discussion of this issue see Working Paper VI.) The mineral resources of the public lands have always been open to some degree of private exploitation. There is general agreement that the current mineral tenure systems on federal lands are inadequate. The location-patent system under the Mining Law of 1872 provides little return to the government for the right to exploit federal resources, and provides no mechanism for planned, national development of the minerals on the public domain. The Mineral Lands Leasing Act of 1920 (30 USC 22 et seq. 1970; PL 66-146) and the Mineral Leasing Act for Acquired Lands of 1947 (USC 351 1970; PL 80-382), failed to provide a coherent structure for the development or conservation of minerals on federal lands, and lacked adequate environmental controls. Recently, the Department of the Interior has attempted to correct some of these inadequacies by issuing a set of regulations which are summarized in Table 3.5. These regulations (43 CFR 3041 and 43 CFR 211, 1976) emphasize environmental considerations and incorporate reclamation provisions, including timing requirements and performance standards. The Department of the Interior recently adopted a new federal Energy Mineral Activities Recommendation System (EMARS) (43 CFR 3520). The new system, designed to lease coal in an organized, planned manner, comprises a series of nominations, multiple resource planning, environmental analysis, and tract selection. The procedure allows for significant public involvement at various stages, and requires an environmental impact statement when the leaseholder submits a mining and reclamation plan to the USGS. It is expected that the EMARS process will take approximately four years before leases can be issued under the new procedure, and that it will incorporate the requirements of 43 CFR 3041 (1976) and 30 CFR 211 (1976) as noted above. Most recently, the Coal Leasing Act Amendments of 1976 (S. 391) was passed. This legislation will facilitate new leasing, and sets some environmental safeguards.

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[11] Schlick, D.P. (1975) Health and Safety Hazards of Mining. Oral presentation by D.P. Schlick, Assistant Administrator -Technical Support, Mining Enforcement and Safety, U.S. Department of the Interior, to the Committee on Energy and the Environment, April 17.

For the past five years, repeated attempts to pass a federal surface mine bill have received large majorities in the Congress only to be twice vetoed by President Ford. A similar bill is now pending. All the bills contain requirements for pre-mining planning that would prohibit mining where damage is irreversible. In addition, they require that land be restored to a condition "capable of supporting the uses which it was capable of supporting prior to any mining or higher or better uses" (H.R. 25, 1976). A recent thorough analysis of relevant costs and benefits (Mintz 1976) has found such a strategy "likely to achieve the best balance among the competing values at stake." State laws to regulate surface mining exist in 38 states and range in strength from nearly meaningless to relatively stringent.

In the past, environmental controls on the use of public lands have been comparatively insignificant or ineffective, but as a result of the National Environmental Policy Act (NEPA) of 1969 (42 USC 4321 et seq. 1970; PL 91-190) and of increasing public awareness of environmental issues, the 1970s have brought a new era of attention to the federal coal lands. Section 102 of NEPA requires any federal agency proposing an action that will significantly affect the quality of the human environment to accompany the proposal with a detailed environmental impact statement. This requirement essentially provides for the consideration of environmental factors in making the decision whether to proceed with the proposed action. In examining EPA's fulfillment of NEPA requirements the courts have scrutinized the way in which environmental impact statments are both prepared and used, and have required more than mere pro forma compliance with Section 102(2)(c) (U.S. Congress, Senate 1969).

In passing NEPA, Congress intended to initiate

> . . . a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; [and] to enrich the understanding of the ecological systems and natural resources important to the Nation . . . (42 USC 4321 et seq. 1970).

That NEPA contains a substantive mandate to the federal agencies is clear both from the Act itself and from its legislative history. Section 101(b) states that it is the

> continuing responsibility of the Federal Government to use all practicable means consistent with other essential considerations of national policy, to improve and coordinate Federal plans . . . and programs to achieve several enviromental goals.

According to the Senate Report (U.S. Congress, Senate 1969), NEPA's purpose

> . . . is to establish by Congressional action, a national policy to guide Federal activities which are involved with or related to the management of the environment or which have an impact on the quality of the environment.

In June 1973 the Sierra Club and other organizations brought an action against the federal government, charging that it had failed to carry out its responsibilities under NEPA (*Sierra Club* v. *Morton* 1975). Specifically, the Sierra Club charged that the government, because it had a program to develop the coal resources of the Northern Great Plains, was required to prepare an overall environmental impact statement covering coal development on all federal lands within the Northern Great Plains region, rather than a series of impact statements, each covering only part of the overall development. This suit was finally decided in favor of the government by the Supreme Court.

POSITION OF INDUSTRY

The electric utilities and the coal mining industry maintain that the combined impact of requirements of federal and state health, safety, and environmental protection legislation has been to increase the lead time for development of both underground and surface mines. The industry estimates that the time required for deep mine development after acquisition of coal rights has increased from the historical average of three years to five years. However, some of this longer lead time can be attributed to shortages of equipment unrelated to any legislative requirement. In addition to the longer lead time, industry claims that a greater front and capital investment is needed for preparation of environmental studies, permit applications, and so on, and to acquire equipment necessary to comply with health, safety, and environmental laws and regulations.

Industry endeavor to shift mining activity from eastern to low-sulfur western coals has been explained as a secondary consequence of air pollution regulations. Although western coals are significantly lower in sulfur content than many eastern coals, the differential decreases when adjustments are made for the lower BTU/ton value of the former. It may be noted that an analysis of western coal reserves in BTU/ton, made in the light of EPA's new source performance standards for power plants of 1.2 lb SO_2 per million BTU, indicates that more than half the U.S. low-sulfur coal is actually located east of the Mississippi (Rieber 1973). Whatever the reasons for the shift to the West, the greater distance between source and user will increase transportation costs and energy use. For example, at 0.7 cents/ton mile, the cost of coal transported 1100 miles from the Powder River Basin to the average eastern user would be increased by $7.70 per ton (Allen and Chandler 1976) thus more than offsetting the differential in reclamation costs described below. Given projected needs for increased coal production to meet demands for base-load power generation and for conversion to synfuels, it is reasonable to assume some increased mining activity in the West, but the need for a major shift to the West is not supported by the above considerations.

Opposition of the coal mining industry to stringent environmental laws governing surface mining has emphasized the argument that the costs involved exceed the benefits derived. Moreover, because of the differences in state laws, topography, geology, seam thickness, and so forth, the net costs of reclamation vary according to site. As a result, average reclamation costs are estimated to range from $0.32/ton in the West, through $1.20/ton in the Midwest, to $2.25/ton in Appalachia. The incremental cost of back-to-contour mining in Appalachia is $2.67/ton

(Bohm et al. 1976:47). Some industry representatives claim that, as a consequence, the burden of reclamation falls inequitably and unnecessarily on operators in certain coal mining areas, while other companies are little affected. However, even under the most expensive conditions, i.e., assuming maximum reclamation (back-to-contour) on steep slopes (25°) and a 30:1 overburden-to-coal ratio, maximum receipts necessary ($17.50/ton) to yield a 12 percent rate of return on investment (Nephew and Spore 1976) were found to be less than the average price of coal realized in the U.S. during a contemporary period ($17.83) (Council on Wage and Price Stability 1976). This indicates that were maximum reclamation to be required (as it presently is not), even current coal prices would give a good rate of return on investment.

Industry has claimed that a federal act to regulate strip mining is not needed since most states now have such laws.

POSITION OF ENVIRONMENTAL GROUPS

The public sector concerned with human and environmental health has endeavored to document the costs of unregulated surface mining (or, conversely, the benefits of regulations). Some of these costs, such as destruction of scenic beauty, social stability, and peace of mind, are difficult to express in dollars. Many others, however, are clearly tangible and susceptible to quantification. Damages to land from unregulated surface mining affect not only the land being mined but nearby areas as well. Landslides and erosion cause measurable impacts, such as loss in agricultural productivity or residential value, loss in tourist or recreational potential, decrease in property-tax value, damages to public property (e.g., roads), and adverse effects on regional wildlife populations. Damages to water resources caused by mining include contribution of acid and other pollutants, disturbance of groundwater, and interference with stream channels.

Impacts that may eventually be quantifiable are: the destruction of commercial and recreational fisheries; adverse effects on industrial, municipal, and domestic water supplies; flooding caused by reduction of the carrying capacity of stream channels (and the faster run-off from denuded watersheds); siltation of navigation channels; reduction in storage capacity of reservoirs; and destruction of aquatic and streambank biota with its ultimate effect on the food chain. Environmental groups point out that while the coal industry has documented the costs of meeting regulations, there is very little documentation of the cost of the absence or insufficiency of regulations. In one study, flooding and siltation from strip mining, even after passage of a moderate state law, were shown to result in "short-run" private property damages (i.e., excluding public property damages to roads and bridges) ranging from 39 cents to 74 cents per ton of coal mined, and from $1249 to $1795 per household.[12]

There is great concern among environmental organizations that surface-mine damage to certain areas may be irreversible when topographic and climatic conditions preclude reclamation. "Sacrifice areas" of this sort include the steep slopes of Appalachia, where soil slippage is exacerbated by high rainfall, and certain arid regions of the West, where an earlier NRC study (1974a) has found annual rainfall levels of less than 10 inches to be insufficient for revegetation. Environmentalists are, further, concerned about permanent damage to water resources from mining in certain locations. For example, they charge that recent Department of the Interior regulations for the mining of leased federal coal, which have been described by the industry as environmentally stringent, in fact pay insufficient attention to protecting the West's scarce water resources.

While industry claims that state laws are sufficient to regulate strip mining, it is widely felt (U.S. Congress, Senate 1973a, U.S. Congress, House 1975b) that state regulation has not been adequate in controlling the harmful effects of this activity. Environmentalists have also pointed out that even states that have relatively stringent laws often have poor enforcement, and that there is frequently pressure on such state governments to weaken their laws or regulations in order to compete with neighboring states in attracting mine operators.

DISCUSSION

Energy shortages have focused attention on the need for massive exploitation of the nation's coal resources, both as a substitute for oil and natural gas in base-load electric power generation and as a potential backup replacement for base-load nuclear power generation. Major efforts are under way by government and industry to develop advanced technology for converting coal to liquid and gaseous forms as a replacement for oil and natural gas, and for cleaner burning of the coal through fluidized bed combustion techniques.

National coal production reached a peak of about 631 million tons in 1947. It then declined significantly, reaching a minimum level of 392 million tons in 1954. Since 1970, coal production has increased to about

[12] Bohm, R.A. (1975) Individual and Social Costs of Coal Mining. Presented by Robert A. Bohm, Appalachian Resources Project, University of Tennessee to the Committee on Energy and the Environment.

600 million tons per year (National Coal Association 1975a, U.S. Bureau of Mines [USBM] 1976). It is estimated that U.S. coal production in 1976 will reach a record of 665 million tons, of which 443 million tons will be burned by electric utilities (The Energy Daily 1976). It has been estimated by some that the United States must double that production by 1985 if federal (FEA) projections of demand for energy are to be met while decreasing dependence upon foreign energy sources.[13] At the other end of the scale are scenarios projecting only 18 or 20 percent growth in demand for coal between 1976 and 1985 (Whittle et al. 1976).

Although the greatest portion (77 to 91 percent, according to different estimates)[14] of the nation's recoverable coal reserves are inaccessible to surface mining, the trend in recent years has been increasingly in the direction of surface mining. At present, this method contributes more than half of the coal mined in the United States (National Coal Association 1975b). The principal reason for this trend is that industry's extraction costs, and hence the price of surface-mined coal, are lower (even though environmental costs to society may be higher). Surface mining, which is often feasible with road building machinery, also requires less manpower and specialized equipment than does underground mining. Finally, current common U.S. underground mining methods are generally less efficient than surface mining in terms of resource recovery.

While the relative proportions of coal mined by one or the other of the major extraction methods (surface versus deep mining) is out of proportion with the distribution of existing coal reserves (surface-minable versus deep-minable), this situation could be corrected by shifts toward alternative underground extraction methods, as well as toward more adequate reclamation of surface mines. For example, longwall mining has a resource recovery, productivity, and safety factor much more closely resembling surface mining than conventional deep mining (Merritt and

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[13] A complete list of the publications in FEA's *Project Independence Blueprint* series may be obtained from the U.S. Government Printing Office, Washington, D.C. The National Technical Information Service, Springfield, Virginia, also carries a partial listing of the series.

[14] The lower percentage (77 percent deep-minable) is based on 195 billion tons total "discovered and recoverable" reserves (Oklahoma University 1975) including 45 billion tons surface minable reserves (Oklahoma University 1975, USBM 1971). The higher percentage (91 percent deep-minable) is based on another set of definitions whereby the estimate of recoverable reserves is 1.5 trillion tons (U.S. Congress, Senate 1973b), including an estimated 136.7 billion tons that are surface minable (Westerstrom 1975). An intermediate percentage, 87 percent, can be derived by using the estimate of 297 billion tons for deep-minable coal (Westerstrom 1975:5), instead of the 150 billion (195 minus 45) in the first calculation.

Davis 1977, Nephew 1973, see also Volume 12 No. 13 of Coal Mining and Processing [Blakely, Buntain, and Mason, 1976]). Longwall mining can achieve 90 percent resource recovery (and even now commonly achieves 70 to 80 percent), can yield a productivity of 500 tons per man day, and has an accident rate considerably smaller than half that of room-and-pillar mining Moreover, subsidence, which is sometimes an environmental problem with underground mining, is much more uniform and predictable from longwall than from conventional deep mining. It should also be borne in mind that as requirements for adequate reclamation of surface-mined land increase, the manpower needs and other direct costs of that extraction method will become much more comparable to the costs of deep mining.

Even though by far the greatest portion of our coal reserves is inaccessible to surface mining, it is unrealistic to believe that surface mining will be banned in the near future. In the past, federal regulations may have somewhat increased the lead time and the capital investment for underground mines; surface mines have been less affected. The regulations related to underground mining are largely concerned with occupational health and safety, while those affecting surface operations are as yet less uniform and tend to aim at environmental protection.

Reclamation of land after the coal has been removed is an environmental issue critical to surface mining. There is great anxiety, especially in the West, and in the steep mountains of Appalachia, that without stringent regulations, mining could take place at sites where damage is irreparable, and that the stripped land will be left despoiled, as it was in many of the eastern and central fields.

The total energy required to surface-mine coal averages 1 to 2 percent of the energy content of the mined coal, and reclamation requires only a minor part of total mining energy (Frabetti et al. 1975, Melcher et al. 1976). Thus the energy consumed in reclamation relative to (coal) energy production is on the average negligible and does not tangibly impede coal production (Oklahoma University 1975). However, energy requirements, like the costs of reclamation, are highly variable and site specific. There may be a few locations where energy requirements to reclaim strip-mined land are higher than average, though even there the energy consumed is probably less than 0.2 percent of the energy content of the mined coal.

In the West, water is a key not only to reclamation, but also to land use of larger areas located near mines. Mined areas, unlike those of Appalachia, cannot be regarded as having been reclaimed when they have simply been reshaped and replanted. Their hydrologic function must also be restored. In areas where productive activities, such as ranching, depend on a barely adequate amount of water, any disturbance of that supply—either by direct interference with aquifers or by contamination of groundwater—can be critical.

Considerably more effort must be devoted to the quantification (in terms of dollars) of the physical benefits that will result from improved mining and reclamation procedures. In addition, it will be important to identify some of the social and demographic effects of shifts in the location of mines or methods of mining. Among these are the sharp changes in levels of employment, population shifts, and impacts on minority populations (e.g., Indian tribes). The quality of life of local populations is also affected by noise (blasting, processing, trucks), by possible hazards (floods, landslides), by reduction of local recreational opportunities, and by harm to aesthetic surroundings.

CONCLUSIONS AND RECOMMENDATIONS

The coal reserves of the United States represent the country's largest available fossil fuel source. Development of these reserves is an integral part of national energy planning. For the near term at least, it is not meaningful to make a choice between the two recovery methods—surface and underground—since both will be used to meet energy needs. However, since 77 to 91 percent of the nation's coal reserves cannot be recovered by surface mining, it will be important to institute underground mining methods (e.g., longwall) that yield higher resource recovery than can currently be achieved, and to keep perfecting procedures that will improve health and safety protection. Preplanning of mining sites and methods, as is required by some existing and pending legislation, will no doubt work to the advantage not only of environment and health but also of industry costs.

Our Committee concludes that federal environmental, health, and safety regulations of coal mining have not significantly inhibited the total production of coal (which has grown markedly), although they may have been among the factors involved in the recent big shift from underground to surface mining.

If the federal strip mine bill were to be enacted, there would be, as with any new legislation, institutional adaptation, by both government and private sectors, that would have to take place before critical processes could function smoothly. In the case of coal strip mining, industry planning and design stages will have to incorporate environmental considerations that require proper reclamation. Planning also will be necessary to include lead times for obtaining environmentally-based permits and so on. Governmental agencies will need to develop their levels of expertise so that they can routinely complete environmental impact analyses or otherwise comply with environmental regulations. Once these institutional capabilities are developed, delays (other than normal lead time) in the opening of new surface mines should become minimal.

Costs and energy requirements to meet environmental quality standards are small compared to the value and energy content of coal recovered from surface mines. We have found that there is little reason for concern about the economic or energy costs associated with fully reclaiming surface mines so as to control pollution.

In summary, we conclude that most existing and pending environmental regulations are appropriate to the very serious environmental problems resulting from coal mining. Although there have undoubtedly been instances of delay in opening new mines, mining starts should now fall into place after the initial lag. Future planning will incorporate the increased lead times needed to achieve environmental and health safeguards. Over the long term, we may expect costs of environmental protection to diminish even further in relation to the overall cost of coal. On balance, we find that the benefits of environmental protection from surface-mining activities outweigh the costs and delays in energy production, and that temporary disorder resulting from current restrictions is a necessary price to pay for the future advantages of improved health and safety and an undamaged environment.

Furthermore, the variety of impacts associated with surface mining requires flexible administrative judgment such as is provided for under the requirements of NEPA.

While judicial insistence on full compliance with the procedural dictates of NEPA has been commendable, more attention must be paid to the law's substantive purposes. The preparation of environmental impact statements required under Section 102C of the law was never intended to be an end in itself, but to ensure implementation of the substantive policy mandate embodied in Section 101. Both the agencies and the courts, however, have concentrated on the procedures required by the Act, neglecting the policy objectives of the procedures.

Recent evaluations of the implementation of NEPA (CEQ 1976b, U.S. Congress, House 1975a, 1976d) have generally concluded that signficant procedural reforms have occurred in the federal agencies concerned, with resultant improved consideration of environmental impacts of proposed actions. Yet it is also widely recognized that NEPA's full potential has not been realized. In its March 1976 *Report on the Environmental Impact Statement Process of Federal Agencies*, the Council on Environmental Quality wrote:

> An important duty of the NEPA office is to educate agency personnel—including top management—about NEPA goals, procedures, and possibilities. Agency leaders need a clearer understanding of the potential of the EIS process as a management tool (CEQ 1976b:2).

To achieve its substantive, as opposed to procedural, objectives, NEPA must be regarded as a resource management tool and its mandate applied to broad policy and programmatic actions of the federal government. A necessary first step toward using NEPA in this way is the development of guidelines aimed at realizing NEPA's policy goals and useful to the agencies in making substantive evaluations of federal proposals (see Caldwell 1976, Andrews 1976). Such "policy guidelines" could also be used by the courts in reviewing agency decisions on their merits, a task the courts have thus far been reluctant to perform.

Together with the development of "policy guidelines" the impact statement process should be modified to exploit better its potential for improving agency planning and decision making. Current agency guidelines stress the need for a comprehensive description of the existing environment. This emphasis on description rather than analysis has given rise to a proliferation of environmental impact statements, the sheer bulk of which inhibits their full incorporation into the decision-making process. The analysis of environmental impacts and program alternatives must be improved if the environmental impact statement is to be useful both in agency decision making on a given project and as a tool in resource management. The CEQ (1976b:2) has recommended a streamlining of environmental assessments:

> The core of an EIS should be its analysis of the significant impacts of both the proposed action and reasonable alternatives on the human environment. The purpose of an EIS should be to communicate this analysis to all decision makers and to the public in a form that is clear in content and manageable in size. Descriptive material that is not central to understanding the impact of alternatives should be summarized and referenced or omitted.

Such a shift of emphasis from description to analysis of the significant impacts of proposed federal actions will require the procedural elements of NEPA to be based on a more detailed knowledge of ecosystem health and productivity than is currently available.

Under NEPA, CEQ was "to conduct investigations, studies, surveys, research, and analyses relating to ecological systems and environmental quality" (Section 204[5]). This function was transferred to EPA by Reorganization Plan No. 3 of 1970. Little has been done to implement this minor but vital function of the Act. Research in EPA has necessarily been focused on separate media (air and water) and individual environmental threats (pesticides, solid wastes, noise, radiation) which are the subjects of various laws, passed at different times, but now to be administered together. In fact, as a consequence of the incoherence of pollution control legislation, EPA's program and organization are based on a fragmented view of the environment that is inimical to the holistic view essential for effective management (U.S. Congress, House 1976d; Carpenter 1976).

The need for early preparation of environmental impact statements cannot be overemphasized. It is imperative that the agencies prepare an environmental impact statement far enough in advance for it to be integrated into every important stage in the decision-making process (CEQ 1976b:3). This will help to ensure that the environmental costs of a project are assessed along with its other benefits and costs. It will also help to prevent the delay and additional costs incurred by protracted litigation to enforce full compliance with the decision-making process mandated by NEPA.

Coal surface mining is an issue in which NEPA can be made effective as a policy tool. By early preparation and application of an environmental analysis, NEPA can be used to ease rather than hinder environmentally sound coal production. The Act would therefore become, as its authors intended, a tool for implementing " . . . a national policy which will encourage productive and enjoyable harmony between man and his environment . . . ." The substantive "policy guidelines" for coal development could be formed within the NEPA process to accommodate the dual objectives of environmental protection and energy production.

ISSUE 7
NO SIGNIFICANT DETERIORATION OF AIR QUALITY

Over the past several years one of the major controversies concerning the environment and energy production has been whether the government should take action to prevent the degradation of air quality in areas where the air is still relatively clean, or cleaner than required by the relevant regulations. This controversy has been stimulated, in part, by an increasing tendency for utilities to locate new fossil fuel plants in areas where the air is clean and where, consequently, their incremental emissions would not violate the primary and secondary air quality standards promulgated under the Clean Air Amendments of 1970 (42 USC 1857 et seq. 1970; PL 91-604). It is often difficult or impossible to locate new power plants in heavily developed or industrial areas where air quality is already at or even in violation of standards. The trend can be seen most dramatically in the recent energy developments in the

Southwest and in the Northern Mountain states, but it has also occurred elsewhere. Thus emissions in the less polluted areas have risen sharply since 1970 (U.S. EPA 1974d).[15] The new emphasis on increasing the role of coal energy production, together with increasing demand for electricity and improved electric power transmission technology, is likely to accelerate this trend in coming years unless actions are taken soon to protect remaining high-quality air sheds.

Concurrently with this movement of new energy facilities toward areas where air is less polluted, public awareness has grown of the environmental consequences of air pollution. (See Working Paper VII for a detailed discussion of the issue.) Aesthetic concerns and increasing scientific understanding of the effect of certain air pollutants on human health, ecosystems, and materials (see Chapter 2) have resulted in the evolution of air quality maintenance as an important social, political, and scientific issue. A growing body of evidence suggests, for example, that pollution at concentrations below the levels allowed by the national primary and secondary air quality standards may be associated with injury to human health and with decreased productivity of agricultural lands and terrestrial and aquatic ecosystems. Data developed since EPA set its air quality standards in 1971 (for instance, new findings about transport and transformation of sulfur oxide and its interaction with ozone to produce synergistic health effects) provides stronger evidence for linking air pollution with human diseases (see Chapter 2).

In May 1972 the Sierra Club (*Sierra Club* v. *Ruckelshaus* 1972) brought suit to force EPA to promulgate regulations requiring state air-quality plans to include measures protective of air quality in areas with very clean air (in addition to meeting goals of attaining and maintaining national ambient air quality standards). The lower courts found in favor of the Sierra Club, and the Supreme Court upheld that decision by a 4 to 4 vote in June, 1973. After extensive development and review processes, including the proposal of four alternative approaches to the prevention of significant deterioration of air quality, EPA issued regulations on December 5, 1974 (40 CFR Part 52 1974). Subsequently, the Administration proposed an amendment to the Clean Air Act that would delete the language requiring EPA to prevent the significant deterioration of air quality but, at EPA's request, indicated that some measures to prevent significant deterioration might be acceptable. Everyone agreed that the Congress should address this complex issue and clarify its intent.

Both the House (U.S. Congress, House 1976a) and the Senate (U.S.

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[15] U.S. Environmental Protection Agency (1976) Unpublished briefing on SIP Revisions and SO_2 Emissions from Power Plants, June 15.

Congress, Senate 1976a) have developed proposals for achieving no significant deterioration (NSD) that are based on the model established by the EPA regulations. Both proposals, however, differ significantly in some respects from the EPA regulations; the changes in the Congressional proposals largely tend to be more protective of the environment.

The major differences among the approaches of EPA, the House, and the Senate to significant deterioration are explained in detail in Working Paper VII, prepared for this Committee (see List of Working Papers), and in the EPA briefing on Alternative Policies for the Prevention of Significant Deterioration.[16]

The EPA regulations classify areas as follows:

Class I. Areas in which practically any air quality deterioration would be considered significant, thus allowing little or no major energy or industrial development.

Class II. Areas in which deterioration that would normally accompany moderate, well-controlled growth would not be considered significant.

Class III. Areas in which deterioration would be permitted to allow concentrated or very large-scale energy or industrial development, as long as the national secondary ambient air quality standards are not exceeded.

The regulations further designate, for each air quality class, a permissible incremental change in ambient pollutant concentration. All areas are initially designated as Class II, leaving redesignation to initiatives of the federal land manager or to state and local governments.

The House and Senate proposals differ from each other and from the EPA regulations in the amount of incremental deterioration in air quality they allow for each class, the sources and pollutants covered, the control technology requirements, mandatory requirements for classification of areas, numeric limitations of allowable incremental deterioration, maximum allowed concentration of pollutants, and allowable stack heights. The House bill gives the states a larger part to play in the EPA standard-setting process. The bill, which covers all pollutants covered by the national ambient air quality standards, also provides ceilings for both allowable pollution increments and allowable pollution for the different classes of regions. Under the Senate bill, there would be no Class III designation for areas now cleaner than required by National Standards. Only sulfur dioxide and particulates are covered in the Senate bill. The proposals now being considered in Congress may, however, be extended to curtail emissions of the other pollutants at present regulated under existing national air quality standards. In fact, some of the emission control systems that might be adopted in response to the proposals might have the additional effect of curtailing emissions of other unregulated chemical compounds.

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[16] U.S. Environmental Protection Agency (1976) Unpublished briefing on Alternative Policies for the Prevention of Significant Deterioration and Related Issues, July 20.

All three proposals provide that the areas of the country where air quality is now better than existing national air quality standards shall be placed in an air quality category, or classification, that is generally more restrictive of pollutant concentrations than are current federal standards. (EPA Class III areas and those Class II areas whose base-year concentrations of pollutants are close to the national ambient air quality standards are excepted.) In the Congressional proposals, classification would be almost entirely within the hands of the states, with the exception of a small group (less than 3 percent) of highly valued federal lands, which would be mandated to remain in the Class I (most restrictive) classification.

In addition, pollution sources covered by the three proposals would be subject to technology standards, although they differ importantly in specific respects. Under the EPA regulations, all major new sources constructed in classified areas are required to install "best available control technology" (BACT). For the 19 categories of sources now regulated under EPA's "new source performance standard" program, meeting these standards would satisfy this requirement. The Senate bill imposes a new requirement to install best available control technology, but this would be defined on a case-by-case basis by each state, with the EPA new source performance standards as a minimum for categories of sources regulated under the existing program. The House bill would require EPA to revise its new source performance standards to require installation of the "best system of continuous emission reduction" available. The committee report on this bill suggests that all new coal-fired power plants would have to install scrubbers to control sulfur oxide emissions. Such a requirement may be viewed as providing an incentive to the electric power industry to develop better pollution prevention technology to replace the scrubbers that industry dislikes. (Under EPA's present new source performance standards, power plants may choose to use low-sulfur fuel, scrubbers, or some combination of these or other measures. To date, most utilities have chosen to meet these standards by maximizing their use of low-sulfur fuel.)

The EPA regulations and the House and Senate proposals have been the subject of numerous studies, both governmental and private, examining their possible effects on economic growth and their cost (U.S.

FEA 1975-1976, Environmental Research and Technology Inc. [ERT] 1975, U.S. EPA 1976e, 1976g, Perl and Fitzgerald 1976a, 1976b). Little, if any, study has been done on their potential environmental benefits. The primary aim of a nondeterioration program would be prevention of significant decrease in the quality of the ambient air. It becomes necessary to define what constitutes a significant net decrease in ambient air quality beyond which deterioration is considered unacceptable.

Preservation of the aesthetics of the physical environment is a primary intent of a program to prevent significant deterioration of air quality. A national commitment to preserve or enhance air quality can also be defended in terms of the reasonableness of avoiding the risks of serious impacts of air pollution on human health and ecosystems. This Committee concurs with these intentions. However, the techniques for achieving nondeterioration must be chosen with care lest the marginal cost for implementing the program exceed the perceived marginal benefits.

Although the potential benefits of curtailing the decline in air quality can be categorically stated as benefits to aesthetics, to human health, and to ecosystems, the evidence on the magnitude of the effects of air pollution is sometimes sketchy or circumstantial. The primary aesthetic benefit of curtailing emissions would be the maintenance of the perceived quality of the environment. For example, exclusion of certain air pollutants, especially particulates (including sulfate particulates) and oxides of nitrogen, would assure clear visibility in aesthetically pleasing areas, such as national parks and wildernesses.

Health benefits will derive from (1) reduced human exposure to the primary regulated pollutants (sulfur oxides, total suspended particulate matter, oxides of nitrogen, hydrocarbons, and carbon monoxide); (2) reduced human exposure to derivative pollutants, such as sulfates, nitrates, and oxidants; and (3) reduced human exposure to other pollutants (e.g., polycyclic aromatic hydrocarbons and trace elements) as a result of their removal by certain of the systems used to control emissions of the primary regulated pollutants. Benefits to the remainder of the ecosystem will be derived from reduced exposure of aquatic and terrestrial ecosystems (such as crops, forests, and fisheries) to the primary regulated pollutants, as well as reduced exposure to acid precipitation. The potential benefits to health and ecosystems from these proposals will accrue both locally, through protection of ambient air quality, and regionally, through the curtailment of pollutants available for long-distance transport.

We cannot be sure that no adverse effects from air pollution exist other than those now apparent. For example, there is reason to suspect that some of the effects of pollutants on human health and ecosystems may have extremely long latency periods, making detection difficult. Nor do we fully understand even those effects already identified. In addition, various chemical and physical reactions are known to produce harmful substances from innocuous ones.

Predicting the cost of various measures to prevent significant deterioration of air quality is also difficult. For the utility industry, for example, the cost of potential control strategies depends critically on the rate of growth in production of electric energy, the proportion of the energy produced from fossil fuels, and the mix of fossil fuels. Prediction is further complicated when, as is the case with all the present proposals, the regulatory tools chosen combine a mix of approaches (for instance, "best available control technology" standards coupled with ambient air quality increments, which are defined as incremental increases in pollutant concentrations over existing levels, as opposed to the air quality standards, which define the limits of ambient pollutant concentrations). It is made even more difficult by the fact that pollution control technology is dynamic, so that predicting costs far into the future on the basis of current technology may result in large errors.

The potential costs of preventing significant deterioration of air quality may, for conceptual purposes, be separated into two types: effects on economic growth and effects on production costs. It has been suggested that some of the regulatory systems proposed might directly impede economic growth in certain areas by preventing the building of major new heavy industrial facilities. Thus, the future pattern of the nation's development could be directly influenced by a nondeterioration program. Significant differences among the costs of alternative sites could face industry with higher production costs or selection of sites that do not maximize the efficiency of the production/distribution systems. It is clear that any effective system to prevent deterioration would add to the cost of constructing such facilities. Assessing the effect on the national and regional economies of increasing the cost of producing the products of heavy industry is extremely complex and requires careful analysis. One possible effect would be to depress sales of the industries most affected and to stimulate substitution by the products of less polluting industries; another would be to increase the demand for the products of the pollution control industry. What the net result of these economic effects will be is not apparent without further analysis of specific cases.

The various proposals to prevent significant deterioration of the environment raise the major issue of the ability of industry to locate where it wishes versus the size and cost of the proposed facilities (see Working Paper VII).

APPROACHES TO PREVENTING SIGNIFICANT DETERIORATION

The Committee has examined six different regulatory approaches for preventing significant deterioration in air quality: ambient air quality standards; "best available control technology" standards; emission standards; emission budgets; auction of emission rights; and emission fees. Some of these concepts are not mutually exclusive, but they have all been separated here for clarity of exposition.

Ambient Air Quality Standards

Ambient air quality standards prescribe limitations on the concentrations of pollutants that will be allowed at ground level. In the context of preventing significant deterioration, such standards could be set to limit increases in the existing ground-level concentration of pollutants in relatively unpolluted areas to some set amount or to some proportion of the existing "background," or to a specified limit of concentrations independent of the level of existing "background." Emission limitations in an area are set implicitly so that maximum concentrations at ground level do not exceed the air quality standards. Ambient air quality standards may require modification or even prevent a source of pollution from operating at a given site, if the source cannot constrain its emissions sufficiently to assure that the standards are not exceeded. Such standards do not specify how the desired level of emission control is to be obtained and thus in theory provide an incentive for the development of inexpensive and effective means of pollution control or of new (and less polluting) production processes.

"Best Available Control Technology" (BACT) Standards

BACT standards call for the use of the best pollution control measures available, without regard to air quality. Depending on the state-of-the-art in pollution control techniques, and how concentrated the sources are in a given area, such a standard might result in more or fewer emissions into the atmosphere than ambient air quality standards. If a specific technology is called for, a BACT standard could discourage technological development.

Emission Standards

Emission standards define the maximum amount of pollutant that can be emitted per unit of activity (e.g., pounds of sulfur dioxide per million

BTU of fuel burned). They can thus establish levels of acceptable pollution, or environmental performance criteria, for pollutant sources on the basis of the productive function performed by each source. Like technology-based standards, they can lead toward more (or less) emission control than might be required by ambient standards. However, emission standards do not necessarily restrict the technological flexibility of the source in choosing the least costly control technique.

Emission Budgets

An emission budget approach would prescribe how much additional pollution could be emitted into the atmosphere over a specified area, which could be local, regional, or even national. Like ambient air quality standards, an emission budget would establish upper limits on the additional pollution of the atmosphere, but with a more direct allocation to the pollution point source. Adopting an emission budget approach implies a social decision to avoid the risks of pollution effects by allowing only a fixed amount of air pollution to occur. Unlike the BACT approach, but like ambient air quality standards, an emission budget provides an incentive to develop inexpensive and effective emission control technology, but only as the limits of the emission budget are reached. After the emission budget is consumed, the allocated increments become very valuable, as new sources of pollution entering the market negotiate to buy existing allocations. Like ambient air quality standards, however, such an approach may result in inefficient government intervention to require retrofitting to "make room" for new industrial development.

Auction of Emission Rights

Emission budget "auctions" establish a process for bidding on pieces of the total emission budget for a given area. Unlike emission budgets which give freely the right to pollute on the basis of "first come, first served," the auction process involves the selling of the pollution rights to the highest bidder. The economic interaction among polluters may be further improved by providing for an "emission broker" who continues to purchase and to sell emission auctions. If there are many sources of pollution and a tight pollution budget, the pollution auctions become expensive. Moreover, sources with poor control technology would have to bid high to obtain the privilege of "using" their proportion of the available air. Sources with more refined control technologies could bid less, because they would be using a smaller portion of the available emission budget. The emission auction approach, in conjunction with an emission budget, could encourage sources to develop improved control technologies. In addition, there would be an incentive for each source to better its emission performance so that it could sell its allocation to new bidders. Thus, there would exist a potentially self-adjusting system for economic expansion within prescribed air quality standards.

Emission Fees

The emission fee is designed to encourage economical emission controls by providing a clear incentive for the development of control techniques less costly than the emission fee. In theory, emission fees could vary from place to place, with higher charges levied to protect especially valued air quality. Unlike ambient air quality or emission budget systems, an emission fee could be designed to induce continuous new technological development, rather than just at the margin when the air quality increment or emission budget had been nearly exhausted. It should be emphasized, however, that emission fees in no way eliminate the need for society to decide how much pollution is acceptable; rather, these decisions would become part of the process of setting the amount of the fee. If the emission fee is not set at the proper level, more or fewer emissions than desired could result.

POSITION OF EPA

Much of the evidence that has occasioned concern over increasing emissions in rural areas has been developed by EPA officials (U.S. EPA 1974d, NRC 1975a). However, the Agency has taken the position that the decision on whether the benefits justify a regulatory program to curtail emission growth in Class I and II areas should be made by Congress.

EPA has examined in considerable detail the economic and energy consequences of the various proposals to prevent significant deterioration (Harbridge House, Inc. 1973; U.S. FEA 1975-1976; U.S. EPA 1976a, 1976g, 1976i, 1976j; Radian Corporation 1976; U.S. FEA 1976, ERT 1976; Enviroplan Inc. 1975). As a result of an analysis, in cooperation with FEA (U.S. FEA 1975), of 74 power plants—about half of those now in the planning stages—the Agency concluded that if these plants were equipped with scrubbers, none of the proposed ambient air quality requirements would have a significant effect on the location or size of the plants. The Agency reported similar findings for a number of other major heavy industries and concluded that the proposed legislation would not preclude the siting of facilities for any category of major source examined (with the possible exception of new copper smelters).

Meeting technology requirements of the more stringent House bill would, in EPA's opinion, slightly increase the cost of production (U.S. EPA 1976i). The utility industry would be the most affected. Assuming that all new coal-fired power plants were required to install scrubbers, the Agency calculated that the total capital and operating costs of the industry would increase between 1.5 and 2.0 percent over the next 15 years. If the present EPA significant deterioration and new source performance standards regulations were retained, the cost increase in 1990 would be about 0.3 percent.[17]

In EPA's view, adoption of the pending legislation to prevent significant deterioration would have little or no effect on the fuel mix of fossil fuel power plants (U.S. EPA 1976f, 1976g). This position contrasts sharply with the contention of a study funded by the Federal Energy Administration (ICF Inc. 1976) that, if coal-fired power plants were required to install scrubbers, utilities would choose instead to construct new oil-fired electric generating plants.

POSITION OF THE FEDERAL ENERGY ADMINISTRATION

FEA opposes the adoption of a policy of no significant deterioration of air quality. The primary basis for FEA's opposition appears to be the energy costs involved and particularly the concern mentioned above about the possible effects of the legislation on power-plant fuel mix and on development of domestic coal resources. In addition to the previously mentioned study of switches from coal to oil (ICF Inc. 1976), FEA has suggested that the ambient air quality standards in the Congressional bills for particulate matter might interfere with the strip mining of western coal.

POSITION OF THE UTILITY INDUSTRY

Representatives of the utility industry take the position that the policy with respect to significant deterioration of air quality should be based on rigorous cost–benefit analysis (Perl and Fitgerald 1975, 1976a, 1976b; Perl and Pace 1975).[18] Substantial sums for pollution prevention should not, in their opinion, be spent to protect against unknown effects. Hence, under conditions of uncertainty, they favor delay until adequate information on health and environmental effects is available, and until more is known about the impacts of higher production costs on the national and regional economies.

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[17] See note 16 above.

[18] Lewis T. Perl, Vice President of NERA, oral communication, 1976.

Although in the early development of the Congressional proposals industry expressed concern that legislation might greatly restrict the number of sites for large coal-fired power plants, this concern has diminished as the legislation has been refined. For the most part, industry appears now to agree with EPA that the Congressional proposals would not markedly affect their ability to site large industrial facilities. Also, industry does not expect the construction of new oil-fired electric power plants in response to NSD regulations.

Utility industry analysts are also generally in agreement with EPA estimates of the cost of the control equipment necessary to meet the requirements of the more environmentally protective House bill (Perl and Fitzgerald 1975, 1976a, 1976b). Most of the disagreement between industry and EPA estimates of cost seems to be accounted for by two factors. First, utility analysts take the position that the Congressional bills will require substantial additional use of low-sulfur coal. It is not clear whether this conclusion derives from a belief that the bills mandate the use of low-sulfur coal, or from the assumption that the use of low-sulfur coal will be necessary to allow the siting of increasingly large power plants. Second, industry analysts assume that under the states' "most probable" interpretation of the proposed law, no single facility will be allowed to consume more than half of the air quality increment at any given site. (Since this would constitute a departure from present state practices with respect to the existing national air quality standards, the Committee doubts that such an interpretation is probable.) The industry analysts have also expressed concern over the effect cost increases related to pollution control might have on economic growth.

POSITION OF ENVIRONMENTAL ORGANIZATIONS

Many environmentalists maintain that none of the proposed Congressional bills strikes the proper balance among environmental protection, economic, and energy goals. They feel that the evidence of risk to public health, ecosystems, and aesthetics justifies curtailing or closely limiting any further increases in emissions, particularly of oxides of sulfur and nitrogen and trace elements. They emphasize the importance of timing to the implementation of a program to limit emissions, pointing out that early legislation can forestall the need for enforcement action later as pollution in clean areas continues to increase. They doubt that the ambient air quality standard approach will curtail further pollution, and they propose that this approach be combined with an emission budget or other more direct approach to curtailing emissions. They also doubt that the air quality classification schemes of the various proposals will adequately protect aesthetic values, and they criticize the proposals for ignoring derivative pollutants and trace elements, which environmentalists regard as more serious threats to health and ecosystems than the pollutants now regulated by national air quality standards.

Many environmental organizations agree with the conclusions of EPA that the proposed legislation will not markedly affect the siting of power plants and other large industrial facilities. They support elimination of the House bill's Class III (least restrictive) classification, on the grounds that the Class II deterioration increment is more than sufficient to allow siting of large coal-fired power plants.

While agreeing with the cost estimates of EPA, most environmental organizations feel that considerably greater protection for the environment could probably be purchased for a relatively small additional cost. They feel that the imposition of more restrictive regulatory programs would stimulate the development of more cost–effective technology, such as more efficient scrubbers, fluidized-bed combustion, or other pollutant removal techniques.

EVALUATION OF POLICY PROPOSALS

It is the Committee's judgment that the result of legislation of the type now under consideration would be a justified commitment of economic and natural resources. The challenge is to select the techniques for preventing significant deterioration that will most effectively accomplish the intents of the EPA and Congressional proposals.

The benefits of the nondegradation proposals are uncertain. In the Committee's view, however, the risks to human health and ecosystems, and the known and potential adverse aesthetic and ecological effects from continuing growth of emissions in relatively unpolluted areas, justify a reasonable expenditure of resources to minimize them. The Committee sees no adequate justification for delaying implementation until better information is available for evaluating the effects of pollutants, and of their transformation and transport to more populated areas. It appears that the cost of the most environmentally protective of these proposals would add no more than about 4 percent to the costs of the most heavily affected industry, the electric utility industry (Perl and Fitzgerald 1975; U.S. EPA 1976i, 1976j).

There appears to be agreement among all interests that none of the nondeterioration proposals will interfere significantly with the siting of electric power plants and other major industrial facilities, if these facilities are fitted with available pollution control technologies. The costs of installing and operating these technologies are large, but not so large as to cause economic dislocations.

The limits on incremental deterioration in air quality included in the proposed legislation will become a factor in choice of sites by utilities and other industries. Thus the proposed legislation would have an influence on land-use decisions similar to that of the present system of ambient air quality standards. Any standard that limits the allowable concentration of pollutants in the ambient air (or on emissions) in a given locality has implications for land use, since at some point the limit can be reached. Our investigation suggests, however, that with the technology currently available, these limits will seldom be reached by facilities of the size now considered economical, and that we are still far from exhausting the technological possibilities for controlling emissions. Thus we believe that the impact of the proposals on land use will be minor in the near future.

The Committee concurs with the judgment of EPA and NERA and considers it unlikely that the Congressional proposals would stimulate utilities to construct many new oil-fired generating plants. The increasing price of oil, possible shortages, and the possibility that the legislation will require installation of scrubbers or use of equally effective emission reduction techniques on oil-fired plants, support this assumption. This intention was explictly stated by the authors of the House bill. Moreover, allowing utilities to shift to oil for intermediate-load new power plants goes against the Congressional goal of lessened energy dependence on oil embodied in the 1974 Energy Supply and Environmental Coordination Act (15 USC 791 et seq. Supp. 1975) and other recent energy legislation.

The contention that the proposed legislation will require greatly increased use of low-sulfur coal is also questioned by the Committee. It seems plain that the proposed legislation would not mandate the use of low-sulfur coal in addition to scrubbers, since authors of both House and Senate bills have explicitly stated a contrary intent (U.S. Congress, House 1976b; U.S. Congress, Senate 1976b). Either the future construction of very large power plants, or regulatory action by the states to require the burning of low-sulfur coal will shift demand to low-sulfur coal. But such developments appear unlikely.

The Committee agrees with the representatives of the utility industry that the production of sludge as a result of the requirement to use the present generation of sulfur dioxide (SO_2) scrubbers is undesirable and may cause difficult waste-disposal and land-use problems. However, the expected quantities of sludge can often be handled by the affected industries, and usually require for their disposal only a small fraction of the total land needed for generating electric energy from fossil fuel (see discussion in Working Paper VII on Rates of Solid Waste Production).

Existing national air quality standards tend to focus on localized effects, rather than regional effects that now are believed by many investigators to be more important. The three proposals to prevent the significant deterioration of air quality represent a legislative recognition of the problem of regional transport of pollutants. However, each proposal has certain weaknesses. The Committee advocates regulation of pollutant emissions or levels and not of the control technology. At present, scrubbers are required, failing to provide for latitude to choose the most economical combination of means of reducing emissions to the desired level. Given the wide disparities in pollutant content of coals in different regions of the country, a uniform national emission standard tends to permit unnecessary pollution in some areas of the country. It may therefore be more realistic and desirable to vary the limits on emissions by region, while leaving the choice of techniques to the industries concerned.

CONCLUSIONS

A nondeterioration program is primarily aimed to preserve the air quality in areas where the air is relatively clean. It also addresses the problem arising from the transport of some pollutants and from the incremental accumulation of point sources, which, though each separately might meet emissions standards, will gradually degrade air quality when aggregated. If no preventive action is undertaken to limit the degradation of air quality, pollution resulting from economic growth will keep increasing until eventually it will exceed ambient standards. Thus, action should be taken to define limits of air quality degradation and allocate permissible emissions of point source pollution.

The Committee concurs with the general principle of minimizing degradation of air quality because: (1) risks to health and ecosystems associated with increasing air pollution may be high (see Chapter 2), and are reinforced by aesthetic considerations; (2) the transport phenomenon implies that degradation of the air anywhere is likely to be a threat to health and the environment in other regions; and (3) the strategy of polluting one air shed and then moving on to the next when ambient levels of pollutants exceed permissible levels is a poor policy.

It is harder to reach unanimous agreement on the definition of the word quality and on the means by which degradation should be minimized than to conclude that preventing significant deterioration is desirable as a general principle. A consensus on techniques cannot be expected, and the Committee is certainly not of one mind as to the best method of preventing significant deterioration. The pros and cons of ambient air quality standards, best available control technology standards, emission standards, emission budgets, auction of emission rights, and emission fees have been discussed. Different members of the Committee have different priorities on these matters. There is, however, a consensus that the technique chosen should stress technological innovation, so that the difficult choices involved in allocating ambient capacity can be minimized. Whatever the technique chosen, there will have to be allocational decisions that will strain institutional and scientific capabilities. It is hoped that new sources and new technologies will operate in such a way as to lead gradually to enhancement rather than to degradation of air quality.

The approach taken by EPA in creating three classes of air quality provides a useful basis for a control strategy. Class I gives a margin of safety to protect pristine areas of great value. Class II allows for a reasonable level of change in the near term. Class III is useful for those areas where the social and economic impact of more stringent controls could do more harm than the change in air quality. Class III areas are viewed by the Committee as areas which have a somewhat longer "grandfather clause" to allow them to clean up more gradually—but the hope is that they would eventually become Class II areas as well.

The success of a proposed regulatory system in achieving its ultimate intent depends strongly on the extent to which it provides industry with incentives to reduce, or prevent, pollution in the most economically efficient manner. Furthermore, the regulatory approach should not allow industry to forestall capital investments by means of time-consuming litigation. The Committee felt that all the proposed regulatory structures aimed at preventing significant deterioration of air quality (as well as the similar structure embodied in present law) fail to provide industry with adequate incentives to develop new technology.

Among the policy alternatives outlined previously, the Committee considered emission fees and emission budget auctions promising for encouraging economic efficiency and the development of new control technology. Unlike emission budgets, which exert pressure for technological innovation only as the budget is exhausted, emission budget auctions can be designed to exert continuous pressure for technological innovation. Ambient air quality standards also exert pressure only as the limits are reached, and only if free air resources are not available in another location. BACT standards discourage innovation by those who might have to pay the cost of installing any newly developed system. Emission standards encourage innovation only up to the point where the standard has been satisfied.

In sum, the Committee concurs with the general principle that deterioration of the air should be avoided. From the array of techniques offered it prefers those that would be most successful in driving technology to meeting more stringent levels of emission. The three-class concept proposed by EPA is useful to protect those areas at the extreme where we do not want to take any risk of degradation (Class I) and where the cost of compliance is not yet feasible to pay (Class III).

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4 Challenges to Management

Efficient environmental management requires that some difficult decisions about allocation of resources be made efficiently by our environmental regulatory agencies, and that our systems of production comply with the allocations at lowest cost. These allocations are made under uncertainties about both the magnitude of the risks involved and the corrective effects of the environmental regulations. The nation's environmental programs generally intend to avoid risks of damage to human health and the environment. The Committee shares the intent of preventing damage to human health and the environment, but views the objectives in a broader framework. Recently, some environmental risks from the production and use of energy and some apparent inefficiencies in our methods for lessening the risks have become clearer. We should review now, in the systems context, how we manage our environment—a question that involves more than how we regulate pollution.

It is argued by some that scientists have not satisfactorily quantified the damage to living things from various pollutants; but although much of our knowledge of effects is imprecise, it provides enough evidence to warrant pollution control. In some cases, however, the scientific evidence is so imprecise that more knowledge may be needed before it should influence environmental management. The production of photochemical oxidants and the transport of air pollutants from region to region, for instance, are phenomena that must be better understood. In general, environmental decision making must be conducted under uncertainty and the environmental manager must be cognizant of all risks and aware of the difference between those that are reasonable to take and those that must be protected against. Ideally, the protection should be accomplished in a way that also conserves resources and uses them effectively.

Once the risk level is established, the objective for resource management becomes the efficient use of energy, material, monetary, and human resources in preventing damage to health and the environment. Establishing acceptable levels of risk poses challenges in different forms: scientific, allocational, and institutional.

SCIENTIFIC CHALLENGES

One of the key problems environmental managers must face is the uncertainty associated with predicting how the environment will respond to energy production and use, how human health and ecosystems will be affected by the residuals generated, and how the measures taken to prevent damage will work. Although considerable evidence now exists of damage from residuals of the various energy systems—evidence that justifies many of our commitments to control—scientific investigations also indicate that pollutants can move about, interact, and accumulate in ways that are not well understood. Furthermore, scientific evidence is, in general, pointing toward greater threats to health from certain pollutants than was anticipated by those who drafted current environmental legislation. We now know that these threats to health and ecosystems are the result of complicated and subtle chemical and physical interactions within the environment. Our limited knowledge of the effects, and the processes that cause them, is a source of frustration to this Committee. Another National Research Council Committee, the Environmental Research Assessment Committee (see Foreword to this report), is studying needs for research in these areas (NRC 1977b, 1977c, 1977d). However, it is essential that, short of absolute knowledge about the extent of damage that can be expected from continued generation of certain pollutants, the scientific community inform those responsible for protecting the quality of the environment of the nature and magnitude of the risks that potentially confront us.

Four major areas of uncertainty have taxed the judgment of the Committee: the transport of pollutants through the media of air, water, and land; the transformation of compounds from harmless chemicals to damaging pollutants in the environment; the synergies through which two or more substances or agents interact to create significantly more damaging substances; and the difficulty of establishing a threshold for effects when even low-level doses are suspect.

THE PROBLEM OF TRANSPORT

Pollutants move through their receiving media in patterns and at rates that often seem capricious and frequently defy measurement. Strategies of air pollution management are confounded by the movement of urban air into rural areas and vice versa. Long-distance transport is a fact of life: for example, the migration of sulfur compounds throughout the region between Chicago and the Atlantic coast has undermined attempts to reduce sulfur oxides in the Northeast. The evidence of long-distance transport has led to the Committee's conclusion that we should be cautious about proposals such as allowing intermittent control strategies for power plants, because the sulfur oxides that would be avoided locally would only be transported to some other site. Thus, while intermittent controls would save abatement-related energy without violating local (ambient) air quality standards, regional air quality could be degraded to an unacceptable level. Although the use of scrubbers (or other continuous emission controls) everywhere appears to be an excessively costly policy when viewed from the perspective of one utility or one location, it may in fact prove a sound strategy when the quality of nationally and regionally significant air sheds is taken into account. Even if we cannot be precise about where transport mechanisms will carry the sulfur oxides, we know that distant populations and ecosystems will be exposed to the effects in some way days and miles from the source. There is also reason to believe that oxidants are carried long distances, so that emissions from various sources may have far greater impact than we now realize.

The transport problem is not confined to air pollution: it exists on a smaller scale with respect to thermal pollution in water bodies, leachates in ground water, bioaccumulation in organisms, and a number of other receiving media for different pollutants. Environmental management is hard pressed to deal with the phenomenon. To predict transport patterns and changes in them over time would take far more regional and national information than we have today. And the quality of this information would have to be good enough for a court of law to accept it as evidence justifying specific state or national pollution regulations. Since we lack this information, it is not surprising that a local environmental manager may believe it is justifiable to trade off stringent pollution controls for the energy that would be consumed in meeting them. The regional perspective, however, might dictate quite a different approach.

THE PROBLEM OF TRANSFORMATION

Sulfur dioxide by itself does not have as significant an impact on human health as its transformation products. Exactly how sulfur dioxide is transformed into sulfates, and whether or not the intermediate stages are more damaging than the final sulfates, is not precisely known. Similarly, nitric oxide is not harmful in itself, but nitrogen dioxide, one of its products, is indeed damaging. Other harmful transformation phenomena are illustrated by the production of the very harmful photochemical oxidants from oxides of nitrogen, hydrocarbons, and various intermediary compounds generated in sunlight, and by one of the products of the sulfur dioxide to sulfates transformation, acid rain, which has serious and identifiable economic consequences in its effects on crops and forests.

Regulation of a substance that is not very harmful per se, but which results in severe effects on health or the ecosystem when transformed in the environment, raises complex management problems. Our knowledge about chemical and physical mechanisms that foster transformations is imprecise, but the consequences of not acting to control the precursors of harmful substances may be more wasteful of human and economic resources than errors made in site-specific pollution abatement decisions. For while a single source of a pollutant may not be significant, the mixing actions within air sheds can accumulate pollutants from several insignificant sources, and transformations can render relatively harmless substances dangerous.

THE PROBLEM OF SYNERGIES

Synergies occur when pollutants interact to produce effects that exceed those of the sum of the individual substances or physical agents acting alone. For example, effects on health are substantially greater when sulfur dioxide and ozone are simultaneously inhaled than the effects of the separate inhalation of each. Synergism also occurs when heated water increases the toxicity of other water pollutants to aquatic organisms.

As is the case with transport and transformation, we know that synergies of pollutant effects exist, but our knowledge of their extent and the conditions that favor them is incomplete. It complicates the task of the environmental manager, who is inclined to establish reasonable single-pollutant standards whereas the information suggests that in the real world protection against harmful effects requires a multiple-pollutant strategy.

THE PROBLEM OF THRESHOLDS

It has long been assumed that chemical pollutants, in contrast to ionizing radiation, become harmful only when they reach a certain level, and that organisms can tolerate low doses without harm. The general weight of evidence, especially with reference to transformation products of sulfur dioxide, is calling that assumption into question. As measurement techniques for low-level doses improve, we are becoming more convinced that scientific evidence does not support the threshold concept, even though standards are now based on it. There is not yet sufficient evidence to call for a major change in standards; but it is appropriate that a process for reviewing existing standards be initiated soon, and that this process recognize new information about effects as it becomes available. Moreover, emphasis should be put on incentives to polluters to reduce or prevent pollution by improving control technology.

The concept of a threshold does have validity as an expression of society's willingness to accept risks below a certain level. For example, when we commission the construction of a bridge or tunnel, we expect injuries and deaths, but safety precautions are used to reduce the number of accidents. If the number of accidental deaths for a certain construction is predicted to be too high, and exceeds the socially-established thresholds of unacceptable risk, the project will probably be rejected or redesigned.

Society has rarely specified its thresholds for risk-taking as clearly as it has for the levels of allowable concentrations of pollutants. It is becoming increasingly unclear whether thresholds in pollution control are in fact based on sound probabilities of damage occurring or failing to occur, and whether the specified thresholds are consistent with the risk. Thus, existing threshold values might not reflect informed decisions to avoid (or accept) prescribed degrees of risk. Some of our air quality standards, for example, may not be defensible either scientifically (they may be inconsistent with similar types of risks) or socially (they may protect against risks that, if specified, society might be willing to accept).

THE CHALLENGE OF RESOURCE ALLOCATION

Environmental managers who seek to make cost–effective decisions and to assure that costs do not outweigh benefits recognize that it is not always administratively or legally possible to achieve precision in pursuing these objectives. This is particularly true at the national level, where the manager must often accept small and local inefficiencies when designing a national system of environmental regulations. Again, administrative simplicity, which is often achieved through uniformity in regulations, is frequently viewed as necessary to assure equitable treatment of polluters. Thus, the criteria of ease or cost of administration and equitable treatment sometimes interfere with the ability of the environmental manager to design the best possible regulatory systems.

The issues in Chapter 3 point up the difficulties in achieving—under the scientific uncertainties outlined above—four important environmental management objectives: low cost–benefit ratios, high cost–effectiveness, administrative ease, and equitable distribution of costs and benefits. (See, for example, the discussion of the first issue in Chapter 3.)

A given cost–benefit ratio may be unfavorable for a specific site or for a particular industrial operation. To permit variances or exceptions without clear cause can, however, weaken an otherwise sound environmental program. Laxity in this respect could give too many polluters the legal right to petition to exhaustion a worthwhile program, for which a cost–benefit ratio might be justified on a national basis. So the criterion of cost–benefit requires a broader view than that of a particular issue or site. Local imbalances or "mistakes" might be justified by the argument that it is administratively or judicially impossible to deal with the subtle nuances of all particular cases. It is necessary to "hold the line." This kind of "bureaucratic centralized" decision will seem irrational to the person who must pay an abatement cost at a site where the cost is clearly not worth paying. Since it is often difficult to prove that the cost is not justified, the individual case falls victim to "the system." This kind of "injustice" is often publicized as an illustration of how insensitive the environmental management system is, when a more sensitive system could be even more costly and difficult to control.

The situation is similar with respect to cost–effectiveness. The Committee finds, for example, that it would be more cost–effective to control medical radiation than to insist on "as low as practicable" (ALAP) levels at nuclear power plants; and, in the case of offshore oil and gas production, to control waste industrial oil and automobile oil in urban runoff instead of the oil in formation waters (see Chapter 3). Cost–effective decisions are difficult to make, for who bears the cost is often as important as the amount of cost to be borne. Thus, for each dollar invested, it may be more effective to control medical radiation, but it is more difficult to deal with the medical industry than it is to deal with the regulated utilities. For each dollar invested it may be better to collect waste oil from service stations and industries than to require oil companies to make additional capital investments in their offshore wells, but it is more difficult. Society finds it more congenial to avoid these troublesome targets, but the Committee believes we are only hiding the costs when we opt for programs that are not cost-effective but merely publicly acceptable or administratively simple.

Administrative ease is a pervasive issue. Often the energy or dollar or time saved would have been worthwhile if only a sensitive administrative system could have been designed to deal with meeting ambient environmental quality standards in site-specific, rather than general, situations. Indeed, most of the shortcomings of applying environmental standards originate in inability to administer (or unwillingness to pay the administrative costs for) a program capable of differentiating among local and regional conditions. It was hoped that giving states powers to implement air pollution regulations would help create a more sensitive program, but the transport problem transcends the jurisdiction of the states. For example, it is clear that New York and New Jersey share air sheds; it is not clear that the two states can work out a mutually beneficial air pollution control program. The regional problem makes it easier to be uniform and more difficult to be locally sensitive.

The complexities of transformation and synergy also modify the information that might be used to justify local variances. From a scientific point of view, it is difficult to justify setting the boundaries of environmental problems to conform to a political jurisdiction where the ability to be locally sensitive may be present. There is pressure to create an environmental management apparatus that can be delicate and discriminating in each circumstance; but as rational as such a system might appear to be, it is also generally conceded to be cumbersome and costly.

This is not to say that uniform regulations are necessarily more cost-effective than varying regulations. That uniform controls usually involve lower administrative costs than varying controls—a fact commonly used to suport uniformity—is hardly conclusive. This is because uniformity will often involve allocative costs that varying regulations would avoid. Such costs result, for example, when all sources are required to control to the same degree even though controlling some more and others less would result in lower total control costs. We have suggested some instances in this report (see Chapter 3). A central question in each case is whether the total costs of controlling and administering uniform regulation are higher or lower than the total costs of varying regulation. Where there are many sources and few technological variables, uniformity is likely to be least expensive on balance; the opposite is probably more often the case where sources are relatively few and the range of control options is broad. The difficult cases lie in between.

The relative cost of uniform versus varying regulations is not the only issue; considerations of equity and fairness also bear on approaches to control. For example, while it may be least expensive to control a pollutant from one source but not another, it might still be considered inequitable to pursue such a course because it would distribute the costs of control unevenly. Similarly, it may often be least expensive in terms of capital expenditures and energy consumption to permit some pollution from multiple small sources while controlling a few major sources stringently, but the major sources will consider this approach inequitable.

Equity considerations are important in final decisions about control, and they must be weighed carefully. Uniformity is almost always thought to be equitable, but it can sometimes be inequitable. For example, some consumers of new automobiles are required to purchase expensive control technology even though that technology may be unnecessary to maintain satisfactory ambient air quality standards in the areas where they live. They must take the expensive and unnecessary technology with the new car primarily because Congress rejected varying emission standards for new vehicles as too cumbersome and costly to administer. Thus all new car buyers must pay for technology needed only in some areas. It is difficult to see the equity in this uniform requirement.

Uniformity can also be inequitable in another sense where it results in unnecessarily costly programs. Distribution of environmental control costs is generally regressive, and the higher the costs the greater the regressive impact.

Thus, the issue of uniformity is complicated, involving both equity and efficiency. Environmental managers should be sensitive to these complications, many of which deny the validity of assuming that uniform controls are preferable. It is possible that varying standards, combined with various sorts of subsidies to redistribute costs, might yield results more consistent with considerations of equity and efficiency.

From time to time state and federal policy makers have considered the use of effluent and emission fees (as well as other market surrogates) as a means to achieve environmental quality standards. Such fees hold promise of achieving varying (and efficient) degrees of pollution control at the source while avoiding many of the high administrative costs and distributional inequities that often attend nonuniform direct controls. (For a fuller discussion see Chapter 3, Issue 7.) Emission and effluent fees and other market surrogates should be given more serious attention and should eventually be implemented on an experimental basis. They could, for example, be tried as one technique to avoid significant deterioration in air quality. The Committee is not urging exclusive reliance on market surrogates to achieve environmental quality, but it believes such devices deserve consideration as one means (together with direct controls and subsidies) toward that end.

Market surrogates encourage controls that minimize total costs of achieving a given environmental quality standard. They are, however, poorly understood. Under an effluent fee program, pollutant sources must pay for the pollutants they emit to the environment, with the result that the total purchases (i.e., the total amount of pollution) can be limited by raising the effluent fee, thus making control a more attractive alternative to the polluter than paying the fee. Direct controls leave less incentive for the polluter to internalize the environmental costs of production as part of his business operation. Under direct controls, once a source is in compliance it pays nothing for those amounts of pollution it emits below the applicable standard. As a result, the source has no incentive to hold pollution below the standard; with an effluent fee it does.

The task of achieving desirable levels of environmental quality in an efficient and equitable manner is exceedingly difficult, and mistakes are to be expected. In the case of trade-offs involving energy and the environment, policy makers and management institutions will need to develop means to make decisions in the face of the sorts of uncertainties the Committee has outlined. The objective of avoiding risks must be attained in a manner that takes into account not only risks to health and ecosystems but also risks that would arise from too meager an energy budget.

MANAGEMENT STRATEGIES

Although the Committee on Energy and the Environment could not pursue policy making and management issues in depth, it discussed, in relation to the nonsignificant deterioration question, some specific management strategies that are worthy of further consideration (see Chapter 3, Issue 7), focusing on the risk-averse approach taken throughout this report. Another National Research Council committee performing analytical studies for the EPA—the Committee on Environmental Decision Making (see the Foreword to this report)—has explored the depth and breadth of the management problem (NRC 1977a). There are, however, six general management strategies that the Committee would like to emphasize here.

EXPERIMENTATION

It is important for the environmental manager to be experimental—to act even without precise knowledge about the potential risk or means of controlling it—in his attempts to solve problems. The manager should also improve the solutions by ex-post analyses and feedback into the management system. In the early 1970s, when the environment came to the public attention with full force, it was necessary and often desirable to move rapidly and apply environmental controls rigidly, to serve industry with notice that society was committed to protecting and improving the quality of the environment. Throughout this period a number of efforts were made primarily for the sake of gathering momentum. Now, however, environmental quality is an established concern, and methods for dealing with its problems, in addition to being more deliberate can and should be more flexible and experimental. This approach is not to be interpreted as an invitation to backsliding. The Committee suggests, rather, that in some cases there are more effective ways to meet our environmental goals than may have appeared feasible in the years of initial concern.

An example of moving forward and then pausing to make evaluations is water quality management under the FWPCA Amendments of 1972, which requires an evaluation of the effects of the legislation. The mid-course corrections of that law provided opportunity to modify the rate and direction of our advance and to arrive at more rational trade-offs. Chapter 3 suggests that a review of other of our various environmental strategies is also in order.

The major potential cost of incorporating experiment and subsequent review into a management system is that it may tempt industry to be nonchalant about deadlines, or cause resources to be wasted in complying with transient regulations. In addition, the courts could be used by antagonists as a vehicle to create delays. But the alternative to experimentation is rigid application of uniform standards that can waste national energy and capital resources in exchange for little environmental benefit.

Historians may view this decade as one in which formerly free resources in our economy were perceived as no longer amenable to free use but were placed instead under the limitations of public influence over resource allocation. Our ability to deal with these new perceptions has developed rapidly but imperfectly. Potentially high risks to human health and the environment mean that we must continue to act in the face of uncertainties. But, because our resources of capital and energy are also precious, we must be willing to abandon ineffectual solutions and find our way to others that work.

ORIENTATION TOWARDS RESULTS

A second recommended strategy for environmental management is to mandate results and not to specify the technology that should be used in achieving them. Such an approach fosters flexibility. It has been attempted in the case of automobile regulations (see Chapter 3, Issue 2). Industry should be informed of the results expected of it; the means for achieving them should be left to the dynamics of the marketplace. While it is true that technology-based standards were useful to get a program moving, they can be costly in the long run by freezing technology and by taking away the incentives to design cost–effective responses. Many of the pollution abatement problems we face today, including cost and energy consumption, result from forcing "end-of-pipe" control technology rather than encouraging redesign of industrial processes. In the future, technological design should incorporate the social values of both a clean environment and energy conservation, avoiding some of the trade-offs among energy, the environment, and the economy facing us today. Automobile technology is evolving in the direction of decreased emissions and better gas mileage. Power generation technologies are advancing in a similar direction. We must set appropriate time schedules and provide incentives to assure that as power stations or automobiles are replaced, new technology will also improve today's inefficient methods for pollution control.

We are better off if we encourage technology to meet the goals of our strategy than if we design our strategy on the basis of available technology (see the discussion of regulations on offshore oil and gas production in Chapter 3, Issue 1). We should retain air and water standards, but allow sources to meet those standards by as many different ways as possible. The Committee's fear is that the approach of requiring polluters to employ "best available technology" will soon become "only orthodox" unless some built-in program of incentives stimulates industry to respond creatively to environmental and energy dictates. If we are to avoid the risk of wasting capital and energy on the one hand, and the risk of laying waste our environment on the other, we must encourage industry to respond through technological innovation.

INCENTIVES TO IMPROVE PERFORMANCE

A third management strategy is to provide incentives to industry to hold pollution levels below current standards, so that economic growth can occur without environmental degradation.

As previously indicated, there is concern that thresholds for health and ecosystem effects are not supported by scientific evidence (see Chapter 2). Thus, our priorities should require formulation of innovative programs that will provide incentives to industry to achieve standards lower than those imposed. Such programs may have to incorporate techniques other than regulatory ones, such as the market surrogates discussed above.

PREVENTIVE MAINTENANCE

A fourth environmental management strategy is to stress preventive maintenance rather than remedial action. Gradually, as society corrects the flaws in a past design that failed to concern itself with the environment and with resource conservation, emphasis should shift to expenditure of capital on prevention techniques. For example, in considering the thermal pollution issue, the Committee has concluded that the problem is not grave at present except in certain local circumstances. This is, however, an opportune time to initiate a program and then to grant exemptions to sources that dispose of their heated water without exposing the aquatic ecosystems to significant risk. This action will permit future facilities to meet the new criteria in the most economic way possible. By having a program ready now, before thermal pollution becomes a serious national problem, we can avoid making irreversible commitments that might exceed the assimilative capacity of our water bodies.

ESTABLISHING PRIORITIES

A fifth management strategy is the establishment of priorities that will give us the greatest environmental return for the energy and capital expended. We would hope, for example, that our discussion of oxides of nitrogen in respect to mobile versus stationary sources (see Chapter 3) would encourage managers to consider sources from the point of view of regional impact. Instead of achieving minimum emissions from one source, it is sensible to determine the cost–effectiveness of a multisource, air and water strategy in which trade-offs among the programs would result in the lowest expenditure of energy and dollars for a desired level of environmental quality.

EFFICIENCY OF RESOURCE PRODUCTION AND USE

A sixth management strategy is the encouragement of resource efficiency in the economy. Materials and energy conservation and resource recovery have become viable methods for reducing the residuals associated with production, consumption, and disposal. However, this ethic of effective resource use, which is the largest context in which NEPA is to operate, has not received the support that aggressive environmental management requires. The hallmark of our seriousness will be the extent to which we discourage energy-intensive lifestyles either by voluntary or mandatory means, and the degree to which we launch programs to achieve re-use of the resources in our "waste" streams. The effects outlined in Chapter 2 indicate that one element of this strategy should be to conserve resources as a means of avoiding impacts on the environment. Resource conservation is an effective way to avoid some of the difficult choices we are faced with in trade-offs between energy and the environment.

CONCLUSIONS

Environmental management based on limiting public exposure to risk should incorporate several essential features. The management system should encourage experiments with new solutions, followed by continuous analysis of results and subsequent feedback into the system. In accomplishing this objective, we should mandate results rather than technology, because this emphasis will encourage innovation to lower the dollar and energy costs in achieving the desired benefits.

It will be particularly necessary to provide incentives to achieve levels even below current standards. The alternative is to tighten regulations continually as effects are discovered and as economic development increases the number of pollution sources. Incentives to move continuously toward better performance are also part of a strategy that focuses on prevention rather than "clean-up," for as regulations become more systematically established, we can turn to avoidance of cost in the future. Priorities will have to be set in areas where it will pay to achieve levels below current standards and where prevention is possible. Such priorities will help us to avoid ineffective expenditure of funds and energy. It is hoped that principles for the establishment of these priorities will be articulated, and that they will meet the overall demands of a policy of reducing risk.

Lastly, consistent with reduction of risks and pollutants as a management strategy, is resource efficiency in the form of conservation and resource recovery and recycling. To the extent that primary standards and the thresholds upon which they are based are insufficient from a risk-averse standpoint, conservation and resource recovery are exceedingly valuable, for they shorten the fuel cycle and its effects, thus forestalling certain of the risks associated with energy systems.

The basic conclusion is that the inevitable trade-offs between energy and the environment are manageable, and that many apparent problems can be solved or mitigated through good resource management. Mistakes can be corrected. the objectives of a rational balance can be defined in the political process, and major risks can be avoided. The larger perspective of resource management embraces values that are perceived to be in conflict and minimizes the conflict through informed action in the present and preventive action for the future.

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APPENDIX

A

Review of Energy Systems, Fuel Cycles, Residuals, and Effects

ENERGY SYSTEMS

An energy system is a sequence of activities from the obtaining of the raw energy resource to the use of the produced energy by the consumer. It includes: a primary energy source, such as coal, petroleum, natural gas, or uranium; the sequence of activities required to obtain the fuel in its raw form; processing; transportation; disposal of its by-products and wastes; central-station conversion of the fuel into energy; and final use of the energy by the consumer. A fuel cycle is only a part of the energy system, and includes the sequence of activities required to obtain and convert the raw fuel into energy.

At present, there are six major energy systems in use and in various stages of development (Oklahoma University 1975): (1) the fossil-fuel energy system, which currently provides the largest proportion of total energy; it can be subdivided according to the various raw fuels (coal, petroleum—including crude oil, shale oil, and tar sands—and natural gas); (2) the nuclear energy system, comprising nuclear fission and nuclear fusion; (3) the hydroelectric energy system; (4) the solar energy system, including direct solar energy, wind, ocean thermal gradients, and growing of plants for energy; (5) the geothermal energy system; and (6) the organic waste energy system, including municipal refuse, agricultural wastes, wood manufacturing residues, sewage sludge, and industrial wastes.

Resource availability and reliability, development technology and implementation, environmental consequences, and economic, social, and political impacts will largely dictate the importance of one energy system relative to another.

The Committee doubts that the hydroelectric, solar, geothermal, and wastes energy systems will make major contributions to energy supply in the next 15 to 20 years.

The energy systems considered in this report are those involving the fossil fuels and the uranium-fission nuclear cycle. The fuel cycles follow this sequence of activities: exploration for the resource, extraction, processing, transportation and storage, central station conversion and transmission, and, finally, use by the consumer. Each of these activities is termed an "element" of the fuel cycle.

Exploration determines whether a particular area contains resources that can be economically extracted and marketed. It usually involves an initial program to identify the existence of sufficient resources of adequate quality, and a second more extensive program to develop the extraction plan.

Extraction involves the surface or underground mining of coal or uranium, and the drilling of onshore or offshore petroleum and natural gas wells and the recovery of their crude resources.

Processing prepares the crude resource for transportation and marketing. Transportation involves the use of special pipelines or carriers, such as tankers, ships, trains, or trucks, to convey the resource to storage points.

Central station conversion burns the fuel to produce electricity or steam. In the case of nuclear fission, light water reactors are used today almost exclusively in this country and will remain dominant until the end of this century. Electrical energy is delivered through a high-voltage network transmitting to main substations, and a low-voltage system distributing to points of use. Overhead transmission is far more common than underground transmission, and tying systems together to create regional power pools makes it possible to achieve equivalent reliability of supply at reduced capacity.

In the nuclear fuel cycle, one additional activity may take place after electrical production, namely, the reprocessing of the fuel. It involves, first, dissolution of the used fuel elements, then removal of the fission products and induced radioactive products, and finally, refabrication of new fuel elements. A recent ban on reprocessing of spent nuclear fuel in the United States for three years or more has been issued by President Ford (The Energy Daily 1976).

Fuel cycles are far more complex and variable than the preceding highly simplified presentation of energy systems can convey. The complexity is well illustrated in the model prepared by the Stanford Research Institute (U.S. ERDA 1975).

There is a broad range of alternative processes to choose from for each of the fuel cycle elements, depending on such factors as type and composition of the products, geographic location, and environmental factors. In the case of coal, for instance, the alternative technologies, or processes, that can transform the raw resource into a useful product number in the tens to hundreds of thousands. Each process yields different quantities and types of residuals with potentially different harmful impacts on health, aesthetics, and the environment.

RESIDUALS AND IMPACTS OF ENERGY SYSTEMS

The primary product of a fuel cycle is energy; residuals are its by-products. They may be chemical compounds, such as oxides of sulfur or nitrogen, or physical agents, such as radiation, heat, or noise. Residuals can be emitted to air, water, or land; thus, their effects are related to their concentration, intensity, and persistence, and to their biological, chemical, and physical action on receptors in the systems they affect. (Residuals from the coal fuel cycle are shown in Table A.1.) Three panels of the Environmental Research Assessment Committee (see the Foreword) have discussed research needs for sources (NRC 1977c), fates (NRC 1977b), and effects (NRC 1977a) of residuals in the environment.

The creation of a residual does not necessarily bring into being a specific effect. Residuals can be managed, altered, or otherwise disposed of so that few, if any, adverse environmental effects occur. Residuals may sometimes be desirable by-products (e.g., petrochemical feedstocks or plutonium as an energy source); and they usually must be managed to prevent uncontrolled release into the environment.

We distinguish between impacts, meaning disruptive influences exerted on the environment, and costs, meaning measures of the response of the environment to those influences.

The impact of a fuel cycle or its component elements is the set of environmental consequences resulting from the management of, or failure to manage, residuals. The term "impact" implies a cause-effect relationship between an energy residual and the receptor it affects. Receptors include organisms and their environment and any physical material, organic or inorganic, that receives the impact of an energy residual. We identify and quantify this cause-effect relationship by developing indicators that can measure the response of the environment to the impact.

Each element of a fuel cycle has potential impacts on health and the

TABLE A.1 An Example of a Fuel Cycle and its Residuals: Coal

Exploration	surface and subsurface physical disturbances noise associated with work crews, drilling, tunneling
Mining - Surface	
Surface preparation:	construction of access roads and facilities maintenance and personnel utilities brought to site vegetation removed
Excavation:	regardless of method large energy requirements, some water requirements, and large outputs of materials energy requirements: electricity, diesel fuel, chemicals and explosives water requirements (small): dust control, fire protection, coal washing and vegetation outputs of materials: coal, solid waste, liquid waste, and air emissions
Mining - Underground	
Surface preparation:	construction of access roads and facilities utilities brought to site cleaning of vegetation from construction site and the location of tunnels or shafts
Excavation:	requires large energy inputs in form of electricity - also use lime (in room and pillar only) outputs include coal, solid waste, liquid waste, and water
Mine Safety - Surface	– same as those associated with any activity involving heavy equipment and the use of explosives
Mine Safety - Underground	– same as surface *plus* ventilation, methane and radon control, general fire and explosion control and roof support
Mine Reclamation - Surface	– dealing with land (surface) disruption: smoothing piles of overburden; restoring surface topography; replacing topsoil; fertilizing; revegetation; and returning land to some productive use (successful revegetation depends heavily on adequate rainfall or irrigation)
Mine Reclamation - Underground	– some surface clean-up (small) - some disposal of materials removed to gain access to the underground coal (small) disposal of materials mined with the coal (major); if not cleaned up, acid drainage results

TABLE A. 1 (continued)

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waste piles (composed of access materials, coal-separated materials, refuse, tailings, slag) must be reclaimed - coal mine waste embankments that impound water and sludge (causing contaminated water and flood hazards because of failures).

subsidence

Surface Mining Residuals (includes reclamation)
Water Pollutants: Acids, bases, total dissolved solids, suspended solids(1)
Air Pollutants: Particulates(2), NO_x(3), SO_x(3), Hydrocarbons(3), CO(3), Aldehydes(3)
Solids (waste and overburden)
Land Disturbances(4)
Occupational Health: Deaths, injuries, man-days lost

Underground Mining Residuals (includes reclamation)
Water: acids, bases, total dissolved solids, suspended solids
Air: none (electrically powered equipment; this does *not* include emissions at power plant)
Solids: non-coal waste (slate, shale, siltstone etc.)
coal waste (from excavation and cleaning)
Land: subsidence and refuse storage sites, water treatment facility

Within and Near Mine Transportation: Surface (primarily trucks over haul roads)
Water: suspended solids
Air: particulates, NO_x, SO_x, HC, CO, Aldehydes
Solids: coal waste including failings and leachates
Land: for haul roads and settling ponds
Noise

Within and Near Mine Transportation: Underground
All zero when rail or conveyors are used (except emissions from rail engines)

(1) principal water pollutant
(2) from wind erosion
(3) from diesel emissions
(4) depends on type of mining but includes: acreage stripped
acreage covered by spoil pile

BENEFICIATION
Breaking and sizing: water required for dust control
land required for facilities
solids generated
Cleaning and washing: water required
refuse pile runoff: acids, total dissolved solids, suspended solids
air: particulates, NO_x, SO_x
solids (fairly large)
land

TABLE A.1 (continued)

(Residuals for new technologies such as gasification, solvent refined, etc. require considerable additional information not reported here.)

TRANSPORTATION

railroads (conventional, unit, dedicated), barges, trucks, pipelines
resources required: additional rights-of-way, new facilities, crews, rolling stock
water: dissolved solids (barges)
air: particulates (wind loss)
no solids
land requirements for rights-of-way

ELECTRIC POWER PRODUCTION (boiler-fired power plant)

water: acids, total dissolved solids, suspended solids, organics, heat (thermal)
air: particulates, SO_x, NO_x, HC, CO, aldehydes, heat
solids: primarily ash
land: required for facilities

(depending on types of controls, can have water consumption, land required for scrubber sludge, etc.)

TRANSMISSION

aesthetic (towers, poles, cables)
land use and physical destruction of the natural vegetation - leads to increased soil erosion
problem of extra-high voltage lines
  relatively high electric fields
  induced magnetic fields

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[1] Principal water pollutant.
[2] From wind erosion.
[3] From diesel emissions.
[4] Depends on type of mining, but includes acreage stripped and acreage covered by spoil pile.

ecology. Thus environmental legislation has been aimed at the impact of each element rather than at the fuel cycle as a whole. A matrix can be set up for each element to show the interrelationships of technology, environmental consequence, and economic cost.

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APPENDIX
B The Energy/Environment Matrix

Environmental impacts of a fuel cycle can be effectively shown by a matrix that records systematically for each step in the fuel cycle the commitments of resources of land, water, air, capital, labor, and energy, and the impacts on health and the environment. The "high," "medium," or "low" values assigned to impacts provide guidance in the comparative assessment of environmental impacts in decision making. Tables B.1 through B.5 illustrate this process. Environmental impacts are shown for the coal, petroleum, natural gas, and nuclear fuel cycles, and their end uses. The first phase of the fuel cycles, the exploration phase, was not included in the matrix because the environmental impacts of that phase are similar to those of extraction but smaller.

DEFINITIONS

THE TERMS

"Resource commitment" indicates the quantity of resources necessary to carry out the fuel cycle processes, including the direct and indirect uses. In some cases, the commitment is permanent, for instance, the land occupied by a deep mine; in other cases it may be temporary or partial, for instance, water used for cooling power plants. Raw materials and finished goods (e.g., steel) are not shown as a separate category but are included in "capital," "labor," and "energy" commitments.

"Land" includes the surface land area either occupied or disturbed by

TABLE B.1 Impacts of the Coal Fuel Cycle

Fuel Cycle Step	Resource Commitment			Ecological Effects	Health Effects	Other Effects
1. Mining and	land	- occupied		land - M		
benefication		subsidence		water - M	accidents - M	recreation - M
		landslides			occupational	land values - M
a. underground	water	- requirement			diseases - M	demographic - M
		siltation/suspended				noise - L
		dissolved solids				indirect - M
		stream capacity				aesthetics - M
		runoff rates	—M			
	air	- dust				
		combustion products				
	capital					
	labor*					
	energy					
b. surface	land	- occupied		land - H	accidents - L	recreation - M
		contour change	—H	water - H	occupational	land values - H
		landslides			diseases - L	demographic - M
	water	- requirement				noise - M
		siltation suspended				indirect - H
		dissolved solids				aesthetics - H
		stream capacity				
		runoff availability				
	air	- dust	—M			
		combustion products				
	capital					
	labor					
	energy					

2. Transportation	land - right-of-way storage canals water - requirement (slurry) -M air - dust combustion products -L capital - M labor - M energy - L	land - M water - barge effects shifts in river basins accidents -L			accidents - H	recreation - M land values - M demographic - L noise - M indirect - L subsidy - M aesthetics - M material damages - L
			With Controls	Without Controls		
3. Power plant	land - M water - M air - M capital - H labor - construction - H operation - L energy - H	land - SO$_X$ NO$_X$ particulates trace metals radioactivity thermal micrometeorology drift	M	H	accidents - L occupational diseases (small) - L gen. community hazards - somatic - H - genetic unknown - L	recreation - L land values - M demographic - M noise - M indirect - M subsidy - M aesthetics - M material damages - H
4. Transmission of electricity	land - occupied construction maintenance -H air - total magnetic field (unknown) ozone -L capital - M labor - M energy - M	land - M water - fish migration indirect -L			gen. community hazards - L	recreation - B land values - M demographic - L noise - M nuisance - M aesthetics - H

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*Both adverse and beneficial effects.

TABLE B.2 Impacts of the Petroleum Fuel Cycle

Fuel Cycle Step	Resource Commitment	Ecological Effects	Health Effects	Other Effects
1. Exploration and drilling	land - L water - L air - combustion products ⎤ blowout ⎥ -M accident ⎦ capital - M labor - M energy - M	land - blowout ⎤ drilling muds (+ oil) ⎥ -L chemical additives ⎥ formation waters ⎦ water - blowout ⎤ drilling muds ⎥ -M chemical additives ⎥ formation waters ⎦	accidents - L occupational diseases - L	land values - B recreation - L demographic - M noise - L indirect - H aesthetics - L material damages - L
2. Production	land - L water - L air - flaring ⎤ NO$_x$, SO$_x$, HC ⎥ -M particulates ⎥ accident ⎦ capital - M labor - L energy - L	land - disposal of formation water ⎤ use of formation water for recovery ⎥ -L seismic disturbances ⎥ pollution of aquifers ⎦ water - formation water] -M	accidents - M occupational diseases - L	land values - B recreation - L demographic - L noise - L indirect - H aesthetics - L material damages - M
3. Transportation (crude, products, gas) a. pipe b. rail c. tanker - d. very large crude carrier	land - M water - from pipe - M from others - L air - NO$_x$, SO$_x$, HC ⎤ particulates ⎥ -L pumping stations ⎦ capital - M labor - M energy - M	land - accidents ⎤ maintenance ⎦ -L water - ballast water from tanker and crude carrier ⎤ BOD, COD ⎥ -L accidents ⎦	accidents - M occupational diseases - L	land values - M recreation - L demographic - L noise - L indirect - M aesthetics - L material damages - L

4. Refining and storage (crude and products)	land - L water - L air - NO_x, SO_x, HC particulates heat micrometeorologic accidents capital - H labor - L energy - M	-M	land - accidents water - COD, BOD, HC phenols, heat accidents	-M -L	accidents - L occupational diseases - L gen. community hazards - M	recreation - L land values - B demographic - M noise - L indirect - M aesthetics - H material damages - M
5. Power plant (with air pollution controls)	land - M water - H air - SO_x, NO_x, HC particulates trace metals micrometeorology capital - H labor - construction - H operation - L	-L	land - drift water - SO_x NO_x particulates trace metals thermal blowdown	-M	accidents - L occupational diseases - L gen. community hazards - somatic - H - genetic unknown - L (small)	recreation - L land values - B demographic - M noise - M indirect - M subsidy - M aesthetics - M material damages - H
6. Transmission of electricity	land - occupied construction maintenance air - total magnetic field (unknown) ozone capital - M labor - M energy - M	-H -L	land - M water - fish migration indirect	-L	gen. community hazards - L	recreation - B land values - M demographic - L noise - M nuisance - M aesthetics - H

TABLE B.3 Impacts of the Natural Gas Fuel Cycle

Fuel Cycle Step	Resource Commitment	Ecological Effects	Health Effects	Other Effects
1. Exploration and drilling	land - L water - L air - combustion products blowout accident capital labor energy —M	land - blowout - M drilling muds (+ oil) chemical additives formation waters —L water - blowout drilling muds chemical additives formation waters —M	accidents - L occupational diseases - L	land values - B recreation - L demographic - M noise - L indirect - H aesthetics - L material damages - L
2. Production	land - L water - L air - flaring NO_x, SO_x, HC particulates accident —M capital - M labor - L energy - L	land - disposal of formation water use of formation water for recovery seismic disturbances pollution of aquifers —L water - formation water - M	accidents - M occupational diseases - L	land values - B recreation - L demographic - L noise - L indirect - H aesthetics - L material damages - M
3. Transportation (crude, products, gas) a. pipe b. rail c. tanker d. very large crude carrier	land - M water - from pipe - M from others air - NO_x, SO_x, HC particulates pumping stations —L capital - M labor - M energy - M	land - accidents maintenance water - ballast water from tanker and crude carrier BOD, COD accidents —L	accidents - L occupational diseases - L	land values - M recreation - L demographic - L noise - L indirect - M aesthetics - L material damages - L

4. Gas liquefaction	land - M water - H air - NO_x SO_x particulates thermal micrometeorology trace metals HC -M capital - H labor - H energy - H	land water - NO_x, SO_x, trace metals, particulates thermal (assume once through) -M	accidents - L occupational diseases - L	land values - B recreation - L demographic - L noise - L indirect - L aesthetics - M subsidy - L material damages - M
5. Power plant (with air pollution controls)	land - M water - L air - SO_x NO_x HC thermal particulates trace metals micrometeorology -L capital - H labor - construction - H operation - L energy - H	land - drift water - SO_x, NO_x, trace metals, particulates blowdown thermal -M	accidents - L occupational diseases - L gen. community hazards - somatic - L - genetic (unknown)	recreation - L land values - B demographic - M noise - M indirect - M subsidy - M aesthetics - M material damages - M
6. Transmission of electricity	land - occupied construction maintenance -H air - Total magnetic field (unknown) ozone -L capital - M labor - M energy - M	land - M water - fish migration indirect -L	gen. community hazards - L	recreation - B land values - M demographic - L noise - M nuisance - M aesthetics - H

TABLE B.4 Impacts of the Nuclear Fission Fuel Cycle

Fuel Cycle Step	Resource Commitment		Ecological Effects	Health Effects	Other Effects
1. Mining and	land - occupied	L	land - L	accidents - L	land values - M
beneficiation	subsidence		water - L	occupational	demographic - L
	land slides			diseases	noise - L
a. underground	water - requirement			- somatic - M	indirect - L
	siltation/suspended			- genetic	aesthetics - M
	dissolved solids			(unknown) - L	
	stream capacity				
	runoff rates				
	air - dust				
	capital				
	labor				
	energy				
b. open pit	land - occupied	M	land - M	accidents - L	land values - M
	land slides		water - M	occupational	demographic - L
	contour changes			diseases	noise - L
	indirect effects			- somatic - L	indirect - L
	water - requirement			- genetic	aesthetics - M
	siltation/suspended	L		(unknown) - L	
	dissolved solids				
	stream capacity				
	runoff				
	water availability				
	capital				
	labor				
	energy				
2. Transportation	land	L	land - L	accidents - L	land values - L
	water		water - L		demographic - L
a. truck	air - combustion products				noise - L
b. rail	capital				nuisance - L
	labor				indirect - L
	energy				subsidy - M

				aesthetics - L material damages - L
3. UF$_6$ production	land - occupied solid wastes]-L fluorides water air - heat combustion products]-M accidents capital - L labor - L energy - L	land water - radionuclides]-L - fluorides	accidents - L occupational and gen. community hazards - L	land values - L demographic - L noise - L nuisance - L indirect - L subsidy - M aesthetics - L material damages - L
4. Enrichment	land - L water - M air - heat fluorides]-M combustion products accidents capital - M labor - L energy - M	land - L water - L	accidents - L occupational and gen. community hazards - L	land values - L demographic - L noise - L nuisance - L indirect - L subsidy - M aesthetic - L material damages - L
5. Fuel fabrication	land - occupied]-M drift water - H air - heat radionuclides]-M micrometeorologic accidents capital - H labor - construction - H operation - L energy - H	land - L water - radionuclides thermal]-M blowdown	accidents - L occupational and gen. community hazards - L	land values - L demographic - L noise - L nuisance - L indirect - L subsidy - M aesthetics - L no material damages

TABLE B.4 (continued)

Fuel Cycle Step	Resource Commitment	Ecological Effects	Health Effects	Other Effects
6. Power plant	land - L water - H air - heat radionuclides micrometeorologic accidents } - M capital - H labor - construction - H operation - L energy - H	land - radionuclides drift } - L water - radionuclides thermal blowdown } - M	accidents - L occupational diseases - somatic - L - genetic (unknown) - L gen. community hazards - somatic - L - genetic (unknown) - L	land values - B demographic - M recreation - L indirect - M subsidy - M long term societal commitment - H aesthetics - L no material damage
7. Transmission of electricity	land - occupied construction maintenance } - H air - total magnetic field (unknown) ozone } - L capital - M labor - M energy - M	land - M water - fish migration indirect } - L	gen. community hazards - L	recreation - B land values - M demographic - L noise - M nuisance - M aesthetics - H

8. Reprocessing	land - L water - L air - radionuclides accidents } -M capital labor - construction - H operation - L energy - L	land water - radionuclides } -L heat	accidents - L occupational and gen. community hazards - L	land values - L demographic - L recreation - L indirect - M subsidy - M aesthetics - L
9. Waste management	land - M water - L air - L capital - M labor - L energy - L	land - L water - L	accidents - L occupational and gen. community hazards - L	land values - L demographic - L recreation - L indirect - M subsidy - M aesthetics - L
10. Decommissioning	Still needs to be determined because of lack of experience.			

TABLE B.5 Impacts of the Automobile End Use (End of Petroleum Fuel Cycle)

	Resource Commitment	Ecological Effects	Health Effects	Other Effects
Automobile end use	land - H water air - NO_X, SO_X, HC CO, H_2SO_4, PAN particulates Pb, heat, asbestos —M micrometeorology gasoline capital - H labor - H	land water - salt gasoline runoff related problems (incl. —H flooding) depression of water table	accidents (includes auto hazards per se - H occupational diseases - H gen. community hazards - somatic - H - genetic (unknown) - L	recreation - B land values - H - B* demographic - H - B* noise - H nuisance - H indirect - H - B* aesthetics - M - B* materials - H

*Both adverse and beneficial effects.

the fuel cycle step. "Water" includes both surface and ground waters and both fresh and salt water. "Air" refers to the deterioriation of air quality due to emissions from the process of the fuel cycle step. "Capital" includes money allocated for the construction, operation, and decommissioning of the required facilities. "Labor" includes the manpower requirement with emphasis on skilled professionals. "Energy" includes the energy requirements for construction, operation, and eventual decommissioning of the facilities.

"Ecological Effects" mean the cumulative effects, both direct and indirect, of the resource commitments and their degradation of ecosystems by residuals. No ecological impacts are shown of the air resource commitments because these are manifested by effects on the terrestrial and aquatic ecosystems. Direct effects of the fuel cycle on man are indicated under "Health Effects." Where particular effects are significant, they are listed separately (see, for example, pollutants listed under the air resource commitment.)

Included under "Other Effects" are impacts on recreational uses, land values, and aesthetics; noise; government subsidies; indirect effects; demographic effects; and material damages. Recreational use, land values, and noise are used in their standard meanings and need no special definition. Aesthetics refers to the appearance of an area. Subsidies refer to externalities of the process, and include direct or indirect public support of a particular portion of the fuel cycle. Indirect effects include legal restraints (e.g., antitrust action), fear of accidents, lack of public acceptance, and similar matters. Demographic effects include changes in population, in the need for public services, and in the tax base of the affected community. In general, demographic impacts are greatest when a new facility is under construction or begins operation with more significant impacts on smaller communities. The impacts tend to decrease as adjustment to the change takes place, but may increase again when the facility ceases operation. Material damages include deterioration due to air pollutants (e.g., damages to rubber, paints, or metals) and the costs of replacement or repair.

THE INDEXES

For deleterious effects, three indexes were used: L = low, M = medium, H = high. For beneficial effects only one index was used: B = beneficial. The indexes were determined on the basis of the extent or severity of the impact, the types of biological response, and the complexity and implications of the biological response. In this analysis, direct and indirect effects and primary, secondary, and synergistic effects have all been considered. The indexes, which are based on the knowledge and judgment of the members of the Committee, reflect both the probability and the severity of an effect, providing some quantitative measure related to the energy output of the fuel cycle. For example, the categories of major impacts for mining of coal and uranium are the same. However, the severity of the impacts is different, being generally smaller for uranium mining which requires smaller quantities of ore to provide an equivalent amount of energy.

The index of the severity of an impact was based on an overall national average, so that impacts that in some cases create severe local or regional problems, were evaluated as less severe on a national basis. Thus, some allowance was made for the site-specific magnitude of impacts. Acid mine drainage, for example, is a severe problem in the mining of eastern coal, but is usually less important for western coal. Similarly, water is not a major problem for energy resource development in the East, but its short supply in the West is an important constraint. Population shifts may have extreme demographic effects on small towns, but usually, not on large ones. Sometimes there may be major differences in effects between initial and later operations at particular sites (e.g., during the construction of a power plant in contrast to its operation). Also, secondary or tertiary effects may be of greater magnitude and importance than primary effects. Good examples of this are siltation and acid mine drainage from surface mining. It is also important to consider the sum of all the impacts, since in some cases many seemingly minor impacts may have the cumulative effect of a large one.

APPENDIX

C

Costs and Benefits of Effluent Regulations on Gas and Oil Operations in Far-Offshore Waters

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SUMMARY

The question posed in this study is whether the proposed EPA effluent regulations for oil and gas production in far-offshore waters are based on a reasonable assessment of environmental benefits on the one hand, and resource, energy, and dollar costs on the other. It was not our intention to debate whether these effluents are detrimental to the far-offshore marine ecosystem but to examine whether these specific regulations promulgated by EPA have a sound technical, scientific, and economic basis.

We have concluded that, in part because of the ambiguity of the law as stated in the Federal Water Pollution Control Act Amendments of 1972 (33 USC 1251 et seq. Supp. 1975; PL 92-500), the regulations—those now in effect and those proposed to take effect in 1977 and 1983—are without scientific or economic validity. They are based on unproven assumptions: that effluents are inherently harmful; that the harm they do warrants a policy of zero-discharge; and that that policy is to be implemented without regard to the effluent's actual effects on the environment, without regard to the social and monetary costs of such a policy, and without regard to the cost-benefit ratio of such a policy. We have found that few pertinent studies have been made and that those that have been made have been ignored during the regulation-making process. The regulations are based solely on technological feasibility, and the desirability or wisdom of achieving a certain level of reduction is not considered. We conclude that regulations so conceived result in unnecessary delay and

unjustified cost increases. There has been no technical, scientific, or economic analysis of the environmental benefits of the regulations, and the existence of such benefits has not been demonstrated.

ENVIRONMENTAL IMPACT OF FAR-OFFSHORE OIL AND GAS PRODUCTION

RESIDUALS DISCHARGED IN OIL AND GAS PRODUCTION

Exploration and Accidents

The environmental impact from regional and detailed exploration surveys is minimal. While explosives are still used onshore, they are no longer used for offshore seismic work, having been replaced by contained detonations and acoustic generators.

The most serious environmental impacts associated with drilling have resulted from accidental blowouts. The number of blowouts during all drilling on land from 1960 to 1970 was 106 out of 273,000 wells, or 0.39 percent, most of which were from high-pressure gas wells rather than oil wells. Offshore, there have been 19 blowouts since 1960 (17 were gas only) which is 0.2 percent of the new wells started (Kash et al. 1973).

Oil Production

Materials with potential environmental impacts are generated during drilling and recovery of the resource. Water residuals from offshore oil extraction are organics (oil) and dissolved solids (brine). Estimates of oil residuals in water/brine range from 1 to 4 tons (7 to 28 barrels) per 10^6 barrels of oil produced. Estimates of dissolved solids range from 0 to 18,000 tons per 10^6 barrels of oil produced (Kash et al. 1973).

The residual of main concern from offshore oil production is the oil contained in the discharged formation water (brine). Estimates range from an oil discharge of 10-50 bbl per million bbl produced (Kash et al. 1973). Without this oil, brine (produced salt water) has been assumed to be nonpolluting when discharged into the ocean (Hittman 1974, 1975). It has been suggested that ideally all wastewaters should be reinjected into the reservoir. However, serious economic burdens and potential environmental impacts are associated with this type of operation. Additional drill holes and energy are required for reinjection and, in view of the lack of scientific and technical data on the ecological impact of these wastes, the additional economic and energy burdens may not be justified.

Natural Gas Production

The considerations involved in the environmental assessment of natural gas production differ somewhat from those involved in crude oil production.

Accidents occur more frequently in natural gas operations than in corresponding crude oil operations, but they generally cause far less environmental damage. For example, water pollution resulting from well blowouts, natural gas pipeline leaks, and malfunctions of gas processing equipment will be much less severe than from similar operations with oil (Battelle 1973).

No water contaminants are generated by any of the modes of extraction, gathering, or processing of natural gas, although some discharge of contaminants such as lubricating oil and caustic wastes could occur in these operations. Thermal discharges may result from operation of natural gas and sulfur extraction plants. The thermal discharge for a natural gas liquids plant is considered to be 25 percent of the energy content of the gas used for plant fuel, or 7.7×10^{9} BTU discharged for each 10^{9} cubic feet (bcf) of natural gas processed. For sulfur removal, the estimate of the thermal discharge (0.8×10^{9} BTU per bcf) is based on a plant designed to treat 60 million cubic feet (mcf) per day of gas containing 6.5×10^{2} grams of H_2S per standard cubic foot of gas.

ECOLOGICAL ASPECTS OF DRILLING AND RECOVERY OF OIL AND GAS OFFSHORE

Drilling Fluids

In the course of drilling an average 15,000-foot well, approximately 110 tons of commercial drilling fluids are used and 950 tons of drill cuttings produced. Drilling fluids include liquids, solids, and gases suspended in liquids. Most common fluids include suspensions of clays and other solids in water (water-based muds), suspension of solids in oil (oil-based muds), oil in water clay emulsions (oil-emulsion muds), and water in oil emulsions (inverted-emulsion muds). Oil-based muds are resorted to only when special problems necessitate their use and do not at present account for more than 5-10 percent of total mud usage.

The composition of these drilling fluids is complex; typical ingredients are materials such as barium sulfate, bentonite clay, hydrated lime, caustic-soda, as well as the common additive ferrochrome lignosulfonate. Additional compounds are used to control properties such as weight (barite), viscosity (carbon methylcellulose), suspension (clay), bactericides (substituted phenols or aldehydes).

EFFECTS OF DISCHARGE OF DRILLING MUDS AND CUTTINGS

The effects of offshore discharge of drilling muds and cuttings have been examined both in the field and in the laboratory. Crockford et al. (1975) have assessed the impact of drilling fluids and formation cuttings in the North Sea. It was assumed that in the area of 1500 square miles with an average depth of 500 feet, 12 rigs each drill one 11,000-foot exploratory hole every two months. It was assumed that the drilling mud materials remain in suspension due to their particle size. Their results are presented in Table C.1. The total suspended solids from drilling operations of 0.12 ppm compares with the naturally occurring suspended solids concentration of 0.1-1.0 ppm. If all of the material from one well were deposited on the bottom, it would result in a covering of 4 cm over a 100 m × 100 m area.

The data presented show that the concentrations of chemicals in this volume of water are well below the measured toxicity levels. However, it is probable that at the point of release concentrations may be above the toxic levels, but with the degree of mixing that will occur in open ocean waters, the critical zone will be small relative to the total area. Since the period of discharge will be limited to a few months, the impacts will be negligible (Crockford et al. 1975). Field observations indicate that the cuttings generally occur within 100 feet of the oil platform, though the suspended drilling mud can be carried by tidal currents. Also, the effects of muds and cuttings from single wells appear to have a small impact upon the immediate area (Zingula 1975, George 1975).

While there may be a degree of burial of benthic biota, the observational data indicate that colonization does take place in relatively shallow waters. While the plume of turbidity from the suspended material is often obvious, the observational data indicate little or no effect. In the Gulf of Mexico suspended materials often cannot be distinguished due to the naturally high turbidity.

However, present-day offshore operations will drill multiple wells (as many as 60) from one platform, resulting in bottom deposits that may eliminate the biota. Immediately below such a platform, drill cuttings could produce a mound 80 to 100 feet in diameter and 20 feet in height. Resuspension and transport of fine material may extend over an area of one-fifth acre to two acres. While this degree of deposition will obviously smother benthic communities, there is observational evidence that spoil are recolonized and the impact in that particular field may overall be less than the deposition from a series of individually spaced wells (George 1975).

Disposal of drilled cuttings when oil muds are used in offshore drillings is a special problem since all free-oil is required to be removed before disposal is allowed. Methods for separating the oil on the platform have been reported (Simpson 1975).

Toxicity of Drilling Fluids

Experimental studies on drilling fluid toxicity have been conducted (Falk and Lawrence 1973, Anderson 1953). Logan and associates (Falk and Lawrence 1973) examined the acute lethal toxicity to trout of several drilling fluids and components. Daugherty (1951) and Anderson (1953) investigated several drilling fluid components under product names. Falk and Lawrence (1973) tested 27 common components of drilling fluids used in the Canadian Arctic. Their 96-hour lethal concentrations (LC 50/96) ranged over a few orders of magnitude (<56,000 to 14.0). Land (1974) in a review concludes that alkaline sources, bactericides, barium sulfate, bentonite, chromium salts, and potassium chloride are the major toxic materials. Chesser and McKenzie (1975) showed that the 96-hour tolerance limit (TL 50/96) for white and brown shrimp exposed to mud additives ranged from 265 to 3500 ppm.

Studies by Zitko (1975) and Weir and Moore (1975) on freshwater fish showed a range of toxicities for low-molecular-weight organic compounds. The high-molecular-weight organic materials were relatively nontoxic. However, all toxicity studies have been conducted on unused materials and little is known about the effects of pressure and high temperatures encountered during the drilling on the materials and additives. The products of these reactions could have higher toxicity than the parent compounds (Zitko 1975).

Produced water from the reservoir recovered during operations may be fresh or saline and contains oil. In offshore situations the oil and water is passed through an oil-water separator mounted on platforms. An average figure for all U.S. fields is six bbl per million barrels produced. A single central separation platform (processing 200,000 bbl per day at 50 ppm oil) may discharge about 1000 bbl of separated oil per year. A calculated discharge-plume would have a maximum surface area of 2 square miles at the 100-ppb oil concentration contour and would extend to an average depth of three feet (CEQ 1974). The resulting effluent may contain a high proportion of water-soluble aromatic compounds that are potentially toxic to marine ecosystems. However, definitive published studies on concentration, composition, and potential toxicity to pelagic species and

TABLE C.1 Mud Chemical Consumption/Contamination from North Sea Exploratory Wells

Chemical	Consumption (11,000–ft Wells)	Consumption 36 × 11,000–ft Wells	ppm in 211 Block from 36 Wells	Toxicity Level (ppm)	"Safety Factor"
Bentonite (lb)	91,000	3,300,000	0.0025	2,800[a]	1,020,000
Barites (lb)	1,205,000	43,500,000	0.0333	2,800[a]	85,000
CMC (lb)	64,000	2,350,000	0.0018	10,000[b,c]	5,560,000
Caustic soda (lb)	32,000	1,200,000	0.0009	33[d]	36,700
Lignosulfonate (lb)	58,000	2,100,000	0.0016	1,500[c]	937,500
"Pozzo" cement (lb)	740,000	26,500,000	0.0203	70[e]	3,450
Other chemicals (lb)	50,000	1,800,000	0.0014	–	–
Formation cuttings (tons)	1,000	36,000	0.0618	–	–

[a] Data from Anderson (1953).
[b] Data from Falk and Lawrence (1973).
[c] Data from Logan et al. (1973).
[d] Data from Portmann (1970).
[e] Data from Daugherty (1951).

SOURCE: Crockford et al. (1975).

benthic biota are lacking, though some laboratory and field studies on brines have been reported by Mackin (1971, 1973).

Reinjection of formation waters is an alternative to disposal because in certain cases it can aid in maintaining oil and gas reservoir pressure and, where it is economically justifiable, can increase ultimate production. It requires the drilling of additional reinjection wells, however, and could potentially pollute freshwater aquifers, damage adjacent oil and gas resources, and produce local seismic disturbances.

Minor Elements Discharged

Produced waters also contain varying quantities of minor elements. Data on measured concentrations of minor elements in formation waters from the United States and Canada (Rittenhouse et al. 1969, U.S. EPA 1975a) show the concentrations of some elements commonly present in oil-field water samples (Table C.2). The median content of total dissolved solids and of various elements varies between areas, in rocks of different ages in the same area, and in different parts of the same formation in a single area. Median values computed to a common salinity base of 35 g/liter indicate Mn, Li, Cr, and usually Sr are present in amounts more than five times their concentration in seawater. In 25 percent of the samples Mn, Cr, and Li exceeded the concentration in seawater by 25 times, Sr by between 5 and 25 times. Co, Cu, Ni, K, Ti, Sn, and V exceed their concentration in seawater by at least two times. It is concluded that except for potassium, the data show no clear relationship between water composition and lithology or age of the enclosing rock and suggest a relationship between composition and salinity of the water (Rittenhouse et al. 1969).

In the majority of cases, the discharge of minor elements to outer continental shelf (OCS) waters is unlikely to result in significantly increased concentrations, because of the degree of dilution that will be achieved on discharge. In some cases, high concentrations of the minor elements Cr, Ni, Co, and V may result in elevated concentrations over limited areas but, until more information is available on the chemical/physical form of these materials in seawater, any assumption on bioavailability or toxicity would be presumptive.

Sewage production on a platform is small. Dry and chemical systems provide alternative systems. Disposal in near-shore waters may be more restrictive than for near-offshore areas depending on the prescribed quality of the receiving waters.

TABLE C.2 Concentrations of Some Elements Present in Oil-Field Water Samples

Concentration	Element
%	Na, Cl
% or ppm	Ca, SO_4
100+ ppm	K, Sr
1-100 ppm	Al, Br, Ba, Fe, Li
ppb (most waters)	Cr, Cd, Cu, Mn, Ni, Sn, Ti, Zn
ppb (some waters)	Be, Co, Ga, Ge, Pb, V, W, Zn, Hg
Total dissolved solids Range 0.8 - 350 g/liter	

SOURCES: Rittenhouse et al. (1969). U.S. EPA (1975a).

FATE AND EFFECTS OF HYDROCARBONS IN THE MARINE ENVIRONMENT

Hydrocarbons

Hydrocarbons in the oceans can originate from biogenic sources, from petroleum introduced via seepage, or from man's activities. Biogenic hydrocarbons as branched- and straight-chain hydrocarbons from C_{15} to C_{33} are generally present in marine organisms and are characterized by an odd-carbon predominance. Pristane and squalene are often present (Blumer 1964, Lee et al. 1971). A recent paper by Blumer (1976) discusses the formation and existence of polycyclic aromatic compounds in nature, though evidence that these compounds are also formed by living organisms is not strong. Blumer suggests that these compounds are generated by natural pyrolytic processes and suggests that the relative uniformity of the polycyclic aromatic hydrocarbon (PAH) fraction in soils and young marine sediments is due to global fallout from forest and prairie fires. In more recent years, PAH compounds have been entering the environment from new sources and in larger amounts than they did in the past. Dominant are those from the incomplete combustion of coal and petroleum and from spillage of crude and refined petroleum. While attempts are being made to assess the effects of this increased loading on man's ecosystems, the potential impact of these natural effects has been ignored. As Blumer (1976) states, "these attempts predate the recent realization that the environmental mixture of aromatic hydrocarbons is exceedingly complex, that it has many sources, that it is difficult to analyze and that main components have never been tested for their biological activity."

The report *Petroleum in the Marine Environment* (NRC 1975) summarizes the work to that date on the input of petroleum hydrocarbons to the sea. Of the six million metric tons per annum (mta) contributed, one-third, or 2.1 mta, is from marine transportation, 1.4 mta from industrial and municipal wastes and urban runoff. River runoff is estimated at 1.6 mta, atmospheric fallout at 0.6 mta, offshore oil production at 0.08 mta, and natural seeps 0.6 mta.

A recent review by McAuliffe (1976) indicates that low-molecular-weight hydrocarbons, principally methane with some C_2–C_4 hydrocarbons, are found throughout the oceans. These gases are mostly biogenic, as are ethene and propene found in the upper 200 m. Higher-molecular-weight hydrocarbons appear to be restricted to the upper 10 m, principally in particulate form, with the concentration decreasing from the air-sea interface. Except for methane, bottom sediments contain low concentrations of C_2–C_7 hydrocarbons. The higher molecular weight hydrocarbons are generally three or four orders of magnitude higher in sediments than in water, with the highest values in the continental shelf.

A recent report by Brown and Huffman (1976) indicates that the median concentration of nonvolatile hydrocarbons in Atlantic water was 4 ppb, with values ranging from 1.3 to 13 ppb. Vertical profile samples showed concentrations of less than 1 ppb for depths of 100 m or more. The qualitative data, however, indicate that hydrocarbons in ocean water have lower aromatic concentration than would be expected if the hydrocarbon source were petroleum. The relative persistence of types of hydrocarbons, in decreasing order, were n-paraffins, cycloparaffins, isoparaffins, and aromatics. While some estimation methods were applied to the data and suggest that hydrocarbons along tanker routes are primarily from petroleum, no explanation can be given to account for the preferential removal of aromatic compounds. The authors conclude that neither evaporation nor dissolution can account for the selective disappearance of C_{14} and heavier aromatic compounds. They suggest that processes such as degradation by chemical and biological reactions or both, or absorption and subsequent sedimentation onto particulate matter, may be occurring.

Acute versus Chronic Discharges

The effects of discharged oil may be acute or chronic. Acute situations are those that occur as the result of accidental spills from tankers, platforms, pipelines, and shoreline facilities. Ecological damage from petroleum and its by-products may occur at the same time as, or at any time after, the appearance of the oil in the environment. The effects may be due to physical action—such as a coating of oil on individual organisms, including birds, shoreline and sea-bottom ecosystems—or to the biochemical effects of toxic components.

Accidental spills constitute only a small fraction of the annual addition of petroleum to the marine environment and occur predominantly in the near-coastal zone, bays, and estuaries. There, concentrations may remain high for extended periods, resulting in far greater impacts than if the oil were released in areas of rapid distribution and dispersion. Coastal areas with low-lying shoreline, enclosed bays, and marshlands are particularly susceptible. These areas are usually productive of marine resources. Such accidents are generally large, and concentrations tend to be higher than those from chronic releases.

Chronic effects are those that result from the continuous release of petroleum or its by-products, from the residues in sediments or marshes following a large accident, or from industrial and municipal discharges. Other activities in the exploration, transportation, and refining phases may also have long-term or chronic effects on ecosystems.

Fate and Effects

Oil and waste effluents produce various levels of biological effects. These have to be accorded different priorities in the evaluation of the impact, depending upon the geographical location, the specific operation, the resource or ecosystem potentially at risk, and the available control technology. These effects include the potential for (1) damage to fishery resources, seabirds, and marine mammals; (2) modification of the ecosystem by elimination of species and decrease in diversity and productivity; (3) damage to habitat to a degree that delays or prevents recolonization; (4) modification of aesthetic environment, usually temporary, due to slicks, oiled beaches, and oiled boats; and (5) hazard to health through eating contaminated seafoods. A more exhaustive review is not attempted here since this is adequately dealt with in many recent publications (NRC 1975, API 1975).

These reviews of the literature and symposia concerning the fate and effects of marine oil pollution show that, despite a plethora of experimental studies on the effects on individuals or small numbers of organisms, there is only a limited number of documented studies that consider the biological, chemical, and physical effects of oil and other related materials in the marine environment. Some studies have been conducted in near-coastal areas, but very few data are available on effects in the open ocean.

Some generalizations on the fate and effects of oil can be made. Following release at discharge, the ultimate fate is dependent on one or more of the following: (1) evaporation to the atmosphere; (2) dispersal and solubility in the water column; (3) incorporation into sediments; (4) oxidation and degradation by chemical or biochemical processes in the water and sediments; and (5) bioaccumulation by organisms from water and sediments, metabolism, retention, and release by organisms. There appears to be little evidence for food web magnification in the case of petroleum hydrocarbons. However, evaluation of the impact of hydrocarbons at levels below those causing immediate toxicity (<100 ppb) requires research into effects of biodegraded products, metabolism, mechanisms of detoxification, elimination, and residence times in lipid pools of various segments of the ecosystem.

Oil spills from tanker accidents have resulted in large amounts of oil being released relative to the size of the affected area. The effects, though in some cases severe, were localized, ranging from a few miles to tens of miles, depending on the environmental conditions. The long-term consequences are still being determined. In the case of the Torrey Canyon disaster in 1967, it is reported that most shores are free of obvious abnormalities. The heavy quantities of seaweeds have at last disappeared, and the limpet populations that resulted from the seaweed quantities have themselves declined because of lack of food. The shores have less algal growth than they did before 1967 because of the recent abundant populations of limpets. It is thought that this reverse swing will lose momentum and produce a more balanced flora and fauna (Marine Biological Association of the United Kingdom 1976). Marshland, saltmarshes, and littoral zones are usually more severely affected. In the case of near-coastal spills from platform accidents, the ecological effects are less severe (McAuliffe et al. 1975), with some immediate effects but no evidence of long-term problems.

Very few studies have been conducted on the effects of operational discharges from platforms, refineries, and tankers. Observational and limited experimental data have indicated that near-shore and offshore platforms have had little impact upon the ecosystem or marine resources. Earlier studies have usually lacked sufficient breadth and depth, analytical support and acceptable experimental design. However, three recent studies in areas subjected for more than a decade to petroleum drilling and production, the Gulf Coast (Morgan et al. 1974) and Lake Maracaibo, Venezuela (Templeton et al. 1975), and California coastal waters (Allan and Moore 1976, McDermott-Ehrilch and Alexander 1976) came to essentially the same conclusions on the impact on the ecosystem. Significant ecological change, detrimental to the system, could not be demonstrated; productivity, including fishery resources, was high; and concentrations of materials related to drilling and production did not appear to pose a significant threat to the ecosystems. In the Gulf studies, the biological variation observed appeared to be a result of natural environmental factors rather than of petroleum drilling and production operations (Morgan et al. 1974).

SUMMARY

From the limited experimental data, it is clear that some of the materials used in or added to drilling fluids are toxic to aquatic biota. However, the types of acute toxicity bioassays conducted allow only for the assessment of relative toxicities and do not provide meaningful data for an assessment of conditions in natural situations. Definitive studies on composition and concentration of these materials from drilling sites is required in order that toxicity tests be conducted at probable concentrations and on organisms potentially exposed.

There is still disagreement on the long-term harm done by minor or major releases of oil. Although large-scale efforts have been directed toward evaluating the fate and effects of released oil in the coastal environment, there is currently little agreement on the ecological significance of localized long-term damage.

Present standards for effluents released from offshore platforms and coastal refineries are general in character. While they appear effective in preventing minor releases of oil to the marine environment, their ecological and economic effectiveness has not been demonstrated. While extensive baseline physical, chemical, and biological data are required before exploration, construction, and operation, either for an environmental impact statement or discharge permits, federal and state agencies and industry appear to have made no extensive attempts to validate their initial assessments in order to provide a basis for future regulatory action.

ENVIRONMENTAL REGULATIONS AND THEIR COST

The sections of the 1972 FWPCA Amendments relevant to the regulation of effluent from both near and far-offshore oil and gas extraction—Sections 301 and 304—set forth a two-step requirement. By July 1, 1977, according to Section 301(b)(1)(A), effluent limitations should be achieved that "require the application of the best practicable control technology [BPT] currently available . . . " This technology is to be defined [Section 304(b)(1)(B)] by taking into account "the total cost of application of technology in relation to the effluent reduction benefits to be achieved . . . ." Thus, consideration of the costs and benefits of regulation is explicitly required by the law. The 1983 requirement, however, makes no mention of cost–benefit ratio [Section 301(b)(2) and Section 304(b)(2)], mandating application of "best available technology economically achievable" (BAT) that will "result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants . . . ."

The zero-discharge goal has been abandoned for far-offshore because of inordinately high predicted energy costs, but in near-offshore (within three miles of shore), the goal remains in effect for 1983, and its achievement is expected to add substantially to the cost of producing oil and gas.

PROPOSED EFFLUENT LIMITATIONS

In response to the requirements described above, EPA has promulgated proposed effluent limitations (U.S. EPA 1975b, 1975c). In its *Development Document for Interim Final Effluent Limitations Guidelines and New Source Performance Standards for the Offshore Segment of the Oil and Gas Extraction Point Source Category*, EPA (1975a) presents the analysis undertaken in support of the proposed regulations. Tables C.3 and C.4, taken from that document, list the proposed effluent limitations for near-offshore and far-offshore subcategories for BPT and for BAT and New Source.

Although more universal in application, the effluent limitations proposed by EPA shown in Table C.3 do not go far beyond current federal and state requirements as shown in Table C.4 at least insofar as 1977 requirements are concerned. Therefore, it is generally difficult to ascribe costs or benefits to the incremental effect of the EPA effluent guidelines alone.

ESTIMATES OF COST

Four types of cost occurring over two different time frames are summarized here from a discussion by Brian Murphy prepared for this Committee.[1] These costs, associated with environmental control of produced waters in both near- and far-offshore waters, are capital and operating dollar costs over both the short term (to 1983) and the long term (beyond 2000); energy consumed in the operation of equipment over the short term (to 1983); potential production losses over the long

[1] Murphy, B.L. (1976) Costs and Benefits Resulting from Proposed and Interim Final Effluent Guidelines for the Treatment and Disposal of Produced Wastes from Offshore Oil Production. Unpublished report to the Committee on Energy and the Environment, Commission on Natural Resources.

TABLE C.3 Oil and Natural Gas Extraction Industry Effluent Limitations (BPT)

		Oil and Grease (mg/liter)		
Subcategory	Water Source	Maximum for Any One Day	Average of Daily Values for 30 Consecutive Days[a] Shall Not Exceed	Residual Chlorine (mg/liter)
A. Near offshore (state waters)	Produced water	72	48	N/A
	Deck drainage	72	48	N/A
	Drilling muds	b	b	N/A
	Drill cuttings	b	b	N/A
	Well treatment	b	b	N/A
	Sanitary M10[b]	N/A	N/A	>1[d]
	Sanitary M9IM[c]	N/A	N/A	N/A
	Domestic	N/A	N/A	N/A
	Produced sand	b	a	N/A
B. Far offshore (federal OCS waters)	Produced water	72	48	N/A
	Deck drainage	72	48	N/A
	Drilling muds	b	b	N/A
	Drill cuttings	b		N/A
	Well treatment	b		N/A
	Sanitary M10[c]	N/A	N/A	>1[d]
	Sanitary M9IM[c]	N/A	N/A	N/A
	Domestic	N/A	N/A	N/A
	Produced sand	b	b	N/A

[a] During any consecutive 30 days, the daily average of four effluent samples shall not exceed the specified value 95 percent of the time.

[b] No discharge of free oil to the surface waters.

[c] There shall be no floating solids as a result of the discharge of these materials.

[d] Minimum of 1 mg/liter and maintained as close to this concentration as possible.

SOURCE: U.S. EPA (1975a).

TABLE C.4 Oil and Natural Gas Extraction Industry Effluent Limitations and BATA and New Source

Subcategory	Water Source	Oil and Grease (mg/liter) Maximum for Any One Day	Oil and Grease (mg/liter) Average of Daily Values for 30 Consecutive Days[a] Shall Not Exceed	Residual Chlorine (mg/liter)
A. Near offshore (state waters)	Produced water	No Discharge		
	Deck drainage	72	48	N/A
	Drilling muds	b	b	N/A
	Drill cuttings	b	b	N/A
	Well treatment	b	b	N/A
	Sanitary M10	N/A	N/A	>1[c]
	Sanitary M9IM[d]	N/A	N/A	N/A
	Domestic[d]	N/A	N/A	N/A
	Produced sand	b	b	N/A
B. Far offshore (federal OCS waters)	Produced water	52	30	N/A
	Deck drainage	52	30	N/A
	Drilling muds	b	b	N/A
	Drill cuttings	b	b	N/A
	Well treatment	b	b	N/A
	Sanitary M10	N/A	N/A	>1[c]
	Sanitary M9IM[d]	N/A	N/A	N/A
	Domestic[d]	N/A	N/A	N/A
	Produced sand	b	b	N/A

[a] During any consecutive 30 days, the daily average of four effluent samples shall not exceed the specified value 95 percent of the time.

[b] No discharge of free oil to the surface waters.

[c] Minimum of 1 mg/liter and maintained as close to this concentration as possible.

[d] There shall be no floating solids as a result of the discharge of these materials.

SOURCE: U.S. EPA (1975a).

term (extending to 2040-2050 or beyond); and steel consumption over the short term (to 1983). Short-term cost estimates were obtained from a study by Cross et al. (1975). Long-term and some short-term estimates were obtained from a study by Arthur D. Little (1975) for EPA. In the Murphy analysis, the dollar costs are, in general, higher than those of the EPA analysis by about a factor of two, but lower in terms of energy requirements. Absolute cost comparisons were difficult to make because of different assumptions about equipment.

Short-Term Costs

The Cross study, which was completed before EPA effluent guidelines were published, estimated equipment requirements for (a) treatment of produced water to an effluent concentration of 72 ppm daily maximum and 48 ppm daily average with discharge to surface waters and (b) subsurface disposal of produced water to attain no discharge. Use of the Cross data to evaluate the EPA proposed and final interim guidelines thus requires the assumption that basically the same equipment can be used to meet BAT and New Source requirements of 52 ppm daily maximum. The study assumes that all underground injection occurs for disposal purposes and not for maintaining reservoir pressure.

Existing discharges were classified by present produced water treatment type, and estimates were made of the fraction of each treatment type unable to meet the daily maximum concentration surface discharge limitation. Equipment requirements for existing facilities to meet the surface discharge limitation were based on a randomly chosen sample of 148 facilities. Also, the additional equipment required to obtain no discharge through subsurface injection was estimated for these 148 facilities.

Equipment requirements for new facilities were based on a typical case for both surface disposal and underground injection using a design water depth and water throughput.

Finally, in expanding the random sample (existing discharges) and typical case (new discharges) to the total number of 1983 Gulf of Mexico and Atlantic discharges, regional effects of water depth and produced water flow rate per discharge were taken into account.

Cross estimates of existing (mid-1975) and new (to mid-1983) discharges are shown in Table C.5. The results of this study on a per discharge basis are shown in Table C.6. Aggregated results for compliance with EPA effluent guidelines in 1983 are shown in Table C.7, which also presents for comparison purposes the cases of all surface discharge and all "no discharge" or subsurface injection. Annual costs are equal to

TABLE C.5 Cross et al. Estimate of Atlantic and Gulf Coast Produced Water Discharges

	To Mid-1975	Mid-1975 to Mid-1983
State waters (near-offshore)	771	[a]
Federal waters (far-offshore)	327	330

[a] Study assumed that the number of new discharges in state waters will be offset by the number of discontinued discharges.

SOURCE: Cross et al. (1975).

operating costs plus capital recovery, assuming a capital recovery factor of 0.17 based on 15-year depreciation, zero salvage value, and 15 percent annual cost of capital. The largest contribution to all cost categories in the case of EPA effluent guidelines is from subsurface disposal at existing discharges in the near-offshore subcategory. This category is responsible for a cost of 940 million 1975 dollars. Existing and new sources in the far-offshore subcategory are responsible for the remaining 260 million 1975 dollars.

The following approximations may be useful in interpreting Table C.7:

26 bcf natural gas/year ≃ Requirements of 400,000 residences
≃ 26 trillion BTU/year
350 million pounds steel ≃ 100,000 automobiles
1.2 billion 1975 dollars ≃ 1 percent of 1973 capital investment of the world petroleum industry (113 billion 1973 dollars [Chase Manhattan Bank 1974])

Long-Term Costs

The Arthur D. Little (1975) study used a lower estimate for equipment costs than Cross et al. and focused on a base case of requirements for bringing Gulf of Mexico wells producing in 1974 into compliance with 1977 and 1983 effluent limitations. Extrapolation to wells producing after 1974 was done by expanding costs by the ratio of reserves implied by 1974 production to USGS reserves.

Table C.8 shows the Arthur D. Little estimate of total investment required by the proposed and interim final EPA effluent guidelines. While a direct comparison with the Cross study is not possible, it appears that

TABLE C.6 Cross et al. Study Results on a Per Discharge Basis[1]

	Capital Cost (10^3 1975 \$)	Operating Cost (10^3 1975 \$/yr)	Energy (mcf gas/yr)	Steel (10^3 lb)
Existing discharge in state waters				
72 ppm daily maximum	93	5.1	.77	21
No discharge	1,200	86.0	32.0	250
Existing discharge in federal waters				
72 ppm daily maximum	150	10.0	1.0	120
No discharge	2,200	180.0	27.0	700
New sources in federal waters				
72 ppm daily maximum	640	36.0	3.3	360
No discharge	4,200	230.0	52.0	1,200

SOURCE: Cross et al. (1975).

NOTE: This table was prepared by the authors of this working paper from information in the referenced report and is not a direct excerpt.

[1] Capital and operating costs as well as energy and steel requirements are larger for new sources than for existing sources in federal waters because new source platforms tend to be bigger, more sophisticated, and further offshore. Numbers in this table are based on a specific set of discharges and cannot be extrapolated to other situations (e.g. Alaskan Gulf).

TABLE C.7 Cross et al. Study Requirements for Proposed 1983 Effluent Guidelines Surface Discharge, and No Discharge Requirements (See Table C.5)

	Capital Cost (10^6 1975 $)	Operating Cost (10^6 1975 $)	Annual Cost (10^6 1975 $)	Energy (bcf gas/yr)	Steel (10^6 lb)
Surface discharge	$ 330	$ 19	$ 75	2.0	170
Proposed and interim final EPA effluent guidelines	1,200	81	285	26.0	350
No discharge	3,000	200	710	51.0	820

SOURCE: Cross et al. (1975).

TABLE C.8 Arthur D. Little Estimates of Total Investment Requirements for Produced Water Effluent Limitations (in millions of 1974 dollars)[a]

	Gulf of Mexico					
	Oil	Natural Gas	Alaska	Atlantic Coast	Pacific Coast	Total
Wells producing before 1977	240	190	–	–	–	430
Wells producing after 1976	130–410		120–1,400	80–160	80–190	410–2,200
Total						840–2,630

[a] Costs are incurred by 1983 for wells producing before 1977. Costs for wells producing after 1976 are expected to be incurred over the period from 1977 to at least 2000.

SOURCE: Arthur D. Little (1975).

the Arthur D. Little requirements for 1983 would be less than a factor of two below the 1.2 billion 1975 dollars shown in Table C.8. In 1975 dollars, the 430 million 1974 dollars incurred by wells producing prior to 1977 would be inflated. In addition a portion of the capital investment of 410-2200 million 1974 dollars incurred by wells producing after 1976 would occur in the 1977-1983 period.

The Arthur D. Little study also estimated the potential production losses due to earlier well closings because of increased operating costs under the effluent limitations. Results are shown in Table C.9. For comparison purposes, U.S. onshore and offshore production in 1972 was 3.4 billion barrels of crude oil and 18.4 trillion cubic feet of natural gas. The potential production losses for oil, therefore, are 4-14 percent and the potential natural gas losses are 6-14 percent of that year's production. It should, of course, be remembered that production losses, if incurred, would extend well into the twenty-first century. The study also notes that, compared to total offshore recoverable resources, the potential production losses are of the order of 1 percent or less for both natural gas and oil.

CONCLUSIONS

The amounts of oil discharged into the offshore waters of the United States by natural gas and oil operations are small relative to the contributions from natural seeps, ship and tanker operations, and river and urban runoff.

The assessment of the impact of effluents from offshore operations has taken only engineering achievability as a basic criterion, without

TABLE C.9 Arthur D. Little Estimates of Potential Production Losses Due to Effluent Limitations[a]

	(Oil in millions of barrels, gas in bcf)									
	Gulf of Mexico		Alaska		Atlantic Coast		Pacific Coast		Total	
	Oil	Natural Gas	Oil	Natural Gas	Oil	Natural Gas	Oil	Natural Gas	Oil	Natural Gas
Wells producing before 1977	51	670	–	–	–	–	–	–	51	670
Wells producing after 1976	25–70	140–560	30–250	100–1,000	20–30	60–150	10–70	50–140	85–420	350–1,850
Total									136–471	1,020–2,520

[a] Production losses are incurred with well closings and are expected to extend to 2040–2050 or beyond.

SOURCE: Arthur D. Little (1975).

sufficient consideration for the scientific and economic factors. No attempt has been made to assess the degree to which ecological impact will be minimized by the proposed regulations. There has been no adequate scientific and technical validation of the basic premise that all materials discharged are pollutants.

The costs of controlling produced water discharges in near-offshore and far-offshore waters are significant in absolute terms but are not disruptive or in themselves unreasonable relative to other industry capital investments or to other uses of national resources. Analysis of the available data shows that by 1985 capital investments will approximate $1 billion. Total capital investments to the year 2000 may approach $2 to $3 billion. The proposed regulations will result in the consumption of about 350 million pounds of steel. The total energy requirements by 1983 will be equivalent to 26 billion cubic feet of natural gas per year, or 26 billion BTU per year. In addition, the potential production losses to the nation, extending to the middle of the twenty-first century may reach 136 to 471 million barrels of oil (4-14 percent of the total 1972 U.S. onshore and offshore production) and 1 to 2.5 trillion cubic feet of natural gas (6-14 percent of 1972 U.S. production).

A general cost–benefit analysis cannot be conducted, since the benefits have not been quantified. Specific regional analyses should be conducted by EPA to define the benefits. On a broader front, cost–effectiveness comparisons should be made between the control of produced water discharges and control of the other major sources of hydrocarbons entering the oceans.

DISCUSSION

While the good intentions of the FWPCA Amendments of 1972 are well recognized, it has become obvious that the national program is not moving forward smoothly. The quality of some of the nation's waters has improved in the years since passage of the Act, but this results from earlier federal, state, and local actions. The recent staff draft report of the National Commission on Water Quality (NCWQ 1975) emphasizes the total economic, social, and environmental effects of achieving or not achieving the goals for 1983.

There would appear to be one primary cause for this delay: the enabling legislation (PL 92-500) to meet those goals was never formulated in detail. However, there are a number of other concerns that prevent application of the Act within the constraints of acceptable economic practice. Uniform national effluent standards, while having a wide appeal as a philosophical concept, are inappropriate for meeting specific or regional water quality needs. The focus of improved water quality is no longer based on specific uses such as potable water, fisheries, and recreation; instead, it is based on a goal of "clean water," a term not defined in the Act, but determined by application of treatment technology or "engineering achievability."

It is obvious that the formulators of this Act and those that implement it in EPA have failed to take cognizance of the expressed purposes of the National Environmental Policy Act of 1969 (42 USC 4321 et seq. 1970; PL 91-190). The preamble to the law itself stated four independent purposes of the legislation (Sec. 2):

> to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the nation; and to establish a Council on Environmental Quality.

As R.A. Carpenter, Executive Director of the Commission on Natural Resources of the NRC has stated, "Thus, the action forcing, procedural elements of the Act (NEPA) were to be concerned with, and undergirded by, a comprehensive knowledge of the environmental sciences" (Carpenter 1976). Unfortunately, in contrast to the procedural developments, the scientific requirements of NEPA, which would have underpinned the FWPCA Amendments of 1972, have been obscured and neglected.

From our examination of the facts presented by EPA in the *Development Guide* (U.S. EPA 1975a) (and some of these comments are equally applicable to other fuel cycles considered in this report), it is apparent that there is an serious lack of proper scientific and technical inputs into the EPA decision-making process. Legalism appears to be taking precedence over proper scientific preparation (Plant 1976) without any supporting evidence to indicate environmental protection or improvement. In the *Development Guide* (U.S. EPA 1975a) emphasis is given to waste treatment. However, the chapter on the selection of pollutant parameters, a critical starting point for derivation of guidelines for the offshore segment, is based upon generalizations that have little scientific supporting data and in many cases are not applicable to the offshore categories. The document illustrates a complete lack of scientific and technical awareness that effluent limitations are necessary only when environmental resources will be potentially affected. This chapter, almost in its entirety, is constructed with qualitative statements of effects but fails to evaluate the readily available data in published reports and in the open literature. It completely ignores the field studies relevant to the subject, it fails to assess the potential impact of these operations in relation to occurring biogenic and related anthropogenic materials discharged to the coastal waters from other sources, and it fails to recognize or apply such obvious parameters as dilution, physical-chemical transformation, and biodegradation that are essential to any assessment of the technical basis of a regulatory action.

More broadly, it is apparent that the regulations are being considered piecemeal without any overall assessment of the impact on the receiving waters. Fetterolf (1975) states, with reference to EPA's thermal regulations, that "The regulations operate under a series of arbitrary constraints without first establishing the necessity of these constraints. We know they are expensive, but we do not know if they are ecologically sound." This statement is equally applicable to the regulations for effluent discharges into offshore waters.

It is pertinent to ask what the real environmental benefits from these regulations can be when it is clear that there are major anthropogenic inputs of petroleum hydrocarbons to our coastal waters from river runoff, urban discharges, and atmospheric deposition. It is more than likely that the implementation of the proposed oil and natural gas regulations would result in negligible ecological and environmental benefits to the marine ecosystem, because of the impact of these other sources. On the other hand, it is not difficult to conceive that there would be real economic and environmental benefits from regulating the collection and refining of waste automobile and industrial oil and grease, a significant part of which inevitably ends up in coastal waters.

RECOMMENDATIONS

- *Existing and proposed effluent limitations for the offshore waters should be reevaluated. Proposed regulatory action should be supported by a strong technical rationale based upon demonstrated and quantified environmental benefits and costs.*
- *The parameters for definition of pollutants should provide for consideration of both natural and anthropogenic sources of pollutants from all sources and the nature of the regional ecosystem potentially impacted.*
- *Adequate baseline data should be obtained so that quantitative environmental benefits can be determined. Where a pollutant is determined to derive from multiple sources, a comparable degree of control should be required for all sources based upon the cost and environmental benefits to be achieved by regulating each source.*

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APPENDIX

D Energy Conversion Factors

Energy Form	Basic Unit	Kcal per Unit	Barrels per Metric Ton	Conversion Factors (million tons of crude oil equivalent to basic unit)
Crude oil	million mt	10,500/kg	7.30	1.0
Refined products	million mt			1.05
LPG	million mt	11,930/kg	11.80	
Gasoline	million mt	11,290/kg	8.53	
Jet fuel/kerosene	million mt	11,330/kg	7.93	
Gas oil/diesel oil	million mt	10,960/kg	7.46	
Residual fuel oil	million mt	10,560/kg.	6.66	
Natural gas	billion m^3	9,000/m^3		0.857
Solid fuel	billion mt	7,000/kg.		0.667
Primary electricity	billion Kwh	860 KWh		0.0820

SOURCE: Energy and Petroleum in Non-OPEC Developing Countries 1974–1980. World Bank Group. Staff Working Paper No. 229 (February 1976).

Efficiencies of Conversion

to electricity ~ 38%
in automobiles ~ 8½%
steam engine ~ 45%
diesel engine ~ 11%

Glossary

acoustic generator: a transducer that converts electrical, mechanical, or other forms of energy to sound.

acid anhydride: an acid with one or more molecules of H_2O removed; e.g., SO_3 is the acid anhydride of H_2SO_4, sulfuric acid.

aerosol: a suspension of liquid or solid particles in the air.

air quality standard: a prescribed level of a pollutant that cannot be exceeded in a specific area during a set period of time.

air shed: the envelope of air encompassing a specific region.

ALAP: as low as practicable.

ALARA: as low as reasonably achievable.

aldehydes: organic compounds used for a variety of substances ranging from fumigants to Bakelite. Aldehydes are one ingredient of smog.

alpha-emitting transuranics: a radioactive material with an atomic number greater than that of uranium that gives off positively charged "alpha" particles; the least penetrating of the 3 common types (alpha, beta, and gamma), usually not dangerous to plants, animals, or man.

ambient concentration: the amount of pollutant in a given volume of ambient air.

anhydride: substances that combine with water to form acids (e.g., organic compounds and inorganic oxides), or substances that can be obtained from acids by the elimination of water.

anthropogenic: of, relating to, or influenced by the impact of man on nature.

anions: negative ion, i.e., atom or molecule that has gained one or more electrons in an electrolyte and therefore is attracted to the positive electrode.

aquifer: the underground layer of water-bearing rock, sand or gravel through which water, seeping down to the ground water table, permeates.

aromatics: hydrocarbons in the benzene series.

background level: the amount of pollutant present in the air due to natural sources, used with respect to air pollution.

background radiation: radiation normally present in the lower atmosphere from cosmic rays and earth sources.

base-loaded: designed to carry only the minimum load of a utility over a given period of time.

BAT/BATEA: best available technology economically achievable.

BACT: best available control technology.

bbl: barrels.

bcf: billion cubic feet.

benthic communities: the floral and faunal populations (benthos) that live upon and contribute to the character of the bottom of a water body.

bioaccumulation: the buildup of a given material in biological systems.

biogenic: produced by the action of living organisms.

biota: the plant and animal life found in a specific region or environment.

blowout: the flooding of oil from the sea bottom during oil well drilling offshore, or during well operation at sea; the gushing of oil above the sea surface.

BOD: biological oxygen demand.

boiling water reactor: a reactor in which water, used as both coolant and moderator, is allowed to boil in the core; the steam can be used directly to drive a turbine.

BPT/BPCTCA: best practicable control technology currently available.

brine: seawater containing a higher than ordinary concentration of dissolved salt.

BTU: British thermal unit.

catalytic converter: an air pollution abatement device that removes organic contaminants by oxidizing them into carbon dioxide and water through chemical reaction.

cation nutrients: particle of a nutrient that is positively charged (see anion).

caustic wastes: waste products with a pH above 7 (basic).

CHESS: Community Health and Environmental Surveillance System, Human Studies Laboratory, Reseach Triangle Park, N.C.; a program of EPA.

Ci: (see curie).

closed cycle cooling systems: designs in which the heat is dissipated by means of a recirculated cooling fluid.

COD: chemical oxygen demand.

cooling tower: a device to remove excess heat from water used in industrial operations, notably in electric power generation.

curie: a measure of the radioactivity in one gram of radium; a curie undergoes 37-thousand-million disintegrations per second.

damage functions: functional relationship between adverse health effects and exposure dose.

daughter: a nuclide formed by the radioactive decay of another nuclide, called the parent.

degradation: the process of breakdown of large organic molecules into smaller ones until the material in question has been changed into inert material on the one hand and stabilized material on the other; the stabilized material is organic material that will not be further degraded or broken down by bacterial action.

direct transaction and control costs: transaction costs are administrative costs, usually incurred by the regulatory agency; control, or compliance costs, consisting of a more complex set of direct cost effects, are the impacts directly related to the production and distribution of the substance at issue.

discharge: any pollutant introduced into the environment; gaseous discharges are usually called emissions, while liquid discharges are called effluents.

dissolved solids: the total amount of dissolved material, organic and inorganic, contained in water or waste.

dose rate effect: a biological effect dependent upon the radiation dose delivered per unit of time.

dual catalyst system: a type of catalytic converter designed to transform automotive exhaust to harmless products; one catalyst oxidizes carbon monoxide and hydrocarbons to water and carbon dioxide; the other reduces oxides of nitrogen to nitrogen gas and oxygen.

ecosystem: the relationships between living things and their nonliving but supportive environment.

effluent: a liquid stream, usually emerging from a processing operation, e.g., sewage and industrial processing wastes.

EGR: exhaust gas recirculation.

end use: the final step in the energy system (q.v.) at which the energy is given its final application.

energy-caused residuals: the by-products, either desirable or undesirable, of energy production; they may be chemicals, such as SO_2 or NO_2, or physical agents such as heat or noise.

energy system: the energy generation process, involving an energy source, such as coal, oil, or uranium; the sequence of activities required to obtain the raw fuel; processing; transportation; conversion of the fuel into energy; and final disposition of its by-products and wastes.

entrainment: when a fluid moving at high velocity carries along other material by virtue of its speed, the captured material is said to be entrained, and the phenomenon is know as entrainment.

eutrophication: the promotion of excessive growth or multiplication of an organism(s) to the disadvantage of other organisms in the same ecosystem by oversupplying it with organic or inorganic nutrients.

FGD: flue gas desulfurization.

fitted linear regression: given two stochastically dependent random variables, regression functions measure the mean expectation of one relative to the other.

flue gas: a mixture of gases resulting from combustion and emerging from a chimney; flue gas includes oxides of nitrogen, oxides of carbon, water vapor, and often oxides of sulfur or particulates.

fluidized bed combustion: a method of burning solid wastes in which they are first shredded or pulverized and then blown into a fire chamber, where they float in the air while oxygen from a fluid-bed not only supports the influent, but also causes it to burn at higher temperatures.

food web magnification: the tendency of materials to reach higher concentrations at higher levels in the food chain.

formation water: water present with petroleum or gas in reservoirs.

fuel cycle: the entire sequence of activities required to obtain and convert raw fuel into energy for any given energy system (q.v.).

fuel cycle element: a discrete sequence of the fuel cycle (e.g., exploration, extraction and reclamation, transportation, processing, conversion to energy, or waste disposal).

fuel element: a rod, tube, plate, or other geometrical form into which nuclear fuel is fabricated for use in a reactor.

hyperplasia: excessive multiplication of cells of the body; an overgrowth of tissue.

intermittent control: a control imposed only during periods of potentially high pollution.

inversion: an atmospheric condition where a layer of cool air is trapped by a layer of warm air so that it cannot rise; inversions spread polluted air horizontally rather than vertically, so that contaminating substances cannot be widely dispersed.

isoline: a line on a map or chart along which there is a constant value (as of temperature, pressure, or rainfall).

LC 50/96: lethal concentration, at which 50 percent of the population is dead after 96 hours.

leachate: liquid that has percolated through solid waste or other media and extracted dissolved or suspended materials from it.

leaching: the process of dissolving out soluble components of a material by the action of a percolating liquid.

light water reactor: a nuclear reactor that uses ordinary water as moderator, in contrast to heavy water.

μg: micrograms.

μg/m^3: micrograms per cubic meter.

market structure costs: the effects of regulations on the number of firms that compose an industry, on the extent to which the production of given products is concentrated or dispersed among firms, and on the search for new products and processes within the industry.

mCi: one thousandth of a curie (37×10^6 disintegrations per second).

mcf: million cubic feet.

MESA: Mining Enforcement and Safety Administration.

morbidity: the ratio of the number of sick individuals to the total population of a community.

mortality: the destruction of individuals in a species expressed in deaths per unit of time.

mrem: millirem (= 1/1000 of a rem—*see* rem).

MWe: megawatt electric; unit of power of nuclear reactors as opposed to thermal power.

MWhe: megawatt hours electric.

MWth: megawatt thermal: unit of thermal power of nuclear reactors.

mta: metric tons per annum.

mutagenesis: The condition in which inheritable genetic changes are passed on from parent to offspring.

NAS: National Academy of Sciences.

natural collector mechanisms: natural processes (e.g., biological, geological, or meteorological) that tend to concentrate given materials at certain locations.

nitrogen fixation: the process whereby bacteria in the soil assimilate atmospheric nitrogen and change it into compounds like ammonia.

nitrogen-fixing nodule: an abnormal nodular growth on a plant root system caused by the establishment of symbiotic nitrogen-fixing bacteria in the host tissue.

NRC: National Research Council; the executive arm of the National Academy of Sciences.

NSD: no significant deterioration/nonsignificant degradation (of air quality).

ocean thermal gradient: a change in temperature from one area of the ocean to another.

OCS: Outer Continental Shelf; that portion of the Continental Shelf that extends from the coastal zone to the edge of the shelf; commonly used to mean the area under federal jurisdiction, from 3 miles out (where state jurisdiction ends) to the edge of the shelf.

oocyte: an ovum prior to the formation of the first polar body; an ovum before maturation; female gametocyte.

overburden: material of any nature, consolidated or unconsolidated, that overlies a deposit of useful mineral ores or coals, especially those deposits that are surface mined.

oxidation catalyst: a substance that increases the rate at which reaction occurs but is itself unchanged at the end of the reaction; as in the catalyst used to convert the incomplete combustion products in motor vehicle exhausts (HC and CO) to water and CO_2.

ozone: oxygen in triatomic form, O_3, found in the earth's atmosphere; a colorless, unstable, pungent gas found as a by-product of photochemical processes; a component of photochemical smog; considered a major air pollutant.

PAH: polycyclic aromatic hydrocarbon.

PAN: (peroxyocylnitrate) one of several photochemical oxidants in the atmosphere, known primarily as an eye irritant.

particulate pollutants: finely divided liquid or solid particles, either organic or inorganic, suspended in the air, in gases, emissions, or in the form of aerosols; they may be introduced into the ambient air from the mouth of a stack, a flue, or a tailpipe, and include dust, smoke, fumes, mist, spray, and fog.

PCI: (see picocurie).

pelagic species: organisms that are free-swimming in the open ocean.

person-rem: the product of the average individual dose in a population times the number of individuals in that population.

photochemical oxidants: secondary pollutants formed by the action of sunlight on the oxides of nitrogen and hydrocarbons in the air; the primary contributors to photochemical smog.

picocurie: a millionth of a microcurie
curie
millicurie $= 10^{-3}$ curie
microcurie $= 10^{-9}$ curie
picocurie $= 10^{-15}$ curie

^{239}Plutonium: isotope of plutonium produced in nuclear reactors; of considerable importance because of its biological toxicity and use as fossil fuel material.

point source: in air pollution, a stationary source of a large individual emission, generally of an industrial nature.

power reactor: a nuclear reactor designed to provide useful mechanical power, as for submarines, aircraft, ships, vehicles, or power plants.

ppb: parts per billion.

ppm: parts per million.

precursor: a substance from which another substance is formed (see also primary and secondary pollutants).

pressurized water reactor: a power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to achieve high temperature without boiling in the primary system; steam is generated in a secondary circuit; many reactors producing electric power are pressurized water reactors.

primary air pollutants: contaminants released directly to the ambient air.

pristine environment: an environment containing no man-made contaminants.

pyrolytic process (pyrolysis): chemical change brought about by the action of heat.

quad: quadrillion, or 10^{15}BTU.

rad: radiation absorbed dose; the basic unit of absorbed dose of ionizing radiation; a dose of one rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material.

radon: a radioactive gas released by the soil into the air; sometimes found as a by-product in the combustion of coal and formed as a gaseous emanation from radioactive decay of radium.

receptor: a living or nonliving object affected by a pollutant.

rem: Roentgen Equivalent, Man; the ionizing radiation that imparts one rad to human tissue.

root knot nematode: a type of unsegmented worm that produces a gall-like enlargement on plant roots.

retrofit: "Retroactive refit"; a modification of equipment to incorporate changes made in later production of similar equipment; may be done in the factory or field.

scrubber: an air pollution device using an atomized spray of water that collides with undesirable particles and traps them; the droplets of water containing the dust and the particulates flow to a demister, where the droplets and their load are separated inertially from the emission, which then flows unpolluted up the stack.

secondary pollutants: when primary pollutants are acted upon chemically or photochemically to create combined, new pollutants, the new pollutants are called secondary pollutants.

settling pond: a natural or artificial pond for recovering solids from an effluent.

sink: any body of water that acts as a long-term repository for pollutants.

skin dose: the dose absorbed on the skin at the center of an irradiation field; the sum of the dose in air and scatter from body parts.

somatic and genetic risks: the degree of probability of damage to body tissues and germ plasm.

suspended solids: the mixture of fine, nonsettling particles of any solid in a liquid or gas; one of the indices used in establishing water quality.

synergism: the cooperative action of two or more separate substances so that the effect on the receptor is greater than the sum of the individual effects.

synergistic response: physiological reaction to a synergistic mechanism (*see* synergism).

synfuels: synthetic fuels.

tcf: trillion cubic feet.

TDS: total dissolved solids.

terpenes: ($C_{10}H_{16}$) hydrocarbons found in essential oils (as from conifers, resins, and balsams).

three-way catalyst system: a type of catalytic converter designed to transform automotive exhausts to harmless products; combines oxidizing and reducing catalysts, an oxygen sensor, and a feedback system.

threshold levels: logicians concerned with pollution frame the threshold question as follows: "Does a pollutant cause poisoning or significant contamination in its smallest quantities, or must a certain threshold be reached before significant harm is done?" The answer is still being debated.

TL 50/96: tolerance limit; the highest concentration at which 50 percent of the organisms are alive after 96 hours.

trace elements: elements vital in minute quantities to the growth and well-being of plants and animals, but toxic above those quantities.

transuranics: (see alpha-emitting transuranics).

U.S. NRC: U.S. Nuclear Regulatory Commission.

whole body dose: the radiation dose to the entire body.

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Bureau of Reclamation, U.S. Department of the Interior, Denver, Colo.
Chevron Oil Field Research Company, La Habra, Calif.
Congressional Research Service, Library of Congress, Washington, D.C.
Council on Environmental Health, Washington, D.C.
Council on Environmental Quality, Executive Office of the President, Washington, D.C.
Development Sciences, Inc., East Sandwich, Mass.
Duke Power Company, Charlotte, N.C.
Edison Electric Institute, Washington, D.C.
Electric Power Research Institute, Palo Alto, Calif.
Environment Policy Center, Washington, D.C.
Environmental Quality Laboratory, California Institute of Technology, Pasadena, Calif.
Environmental Research and Technology, Inc., Concord. Mass.
Exxon Corporation, Linden, N.J.
General Motors Corporation, Warren, Mich. and Washington, D.C.
Government Research Corporation, Washington, D.C.
Greenfield, Attaway, and Tyler, Inc., San Rafael, Calif.

Gulf University Research Consortium, Houston, Tex.
Hittman Associates, Columbia, Md.
Mining Enforcement and Safety Administration, U.S. Department of the Interior, Arlington, Va.
Mitre Corporation, McLean, Va.
National Economic Research Associates, New York, N.Y.
National Environmental Research Center, U.S. Environmental Protection Agency, Research Triangle Park, N.C.
National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health, Education, and Welfare, Salt Lake City, Utah and Rockville, Md.
National Science Foundation, Washington, D.C.
Natural Resources Defense Council (NRDO), Washington, D.C.
New England Electric System, Westborough, Mass.
Oak Ridge National Laboratory, Oak Ridge, Tenn.
Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C.
Office of Technology Assessment, Washington, D.C.
Pan American Health Organization, Washington, D.C.
Rand Corporation, Santa Monica, Calif.
Resources for the Future, Washington, D.C.
Salomon Brothers, New York, N.Y.
Shell Oil Company, Houston, Tex.
Southern California Edison Power Co., Rosemead, Calif.
Stanford Research Institute, Menlo Park, Calif.
Tennessee Valley Authority, Chattanooga, Tenn.
Texaco, Inc., Beacon, N.Y.
United Mine Workers, Washington, D.C.
University of Virginia, Charlottesville, Va.
U.S. Atomic Energy Commission, Washington, D.C.
U.S. Department of Agriculture, Washington, D.C.
U.S. Department of Commerce, Washington, D.C.
U.S. Department of the Interior, Washington, D.C.
U.S. Energy Research and Development Administration, Washington, D.C.
U.S. Environmental Protection Agency, Washington, D.C.
U.S. Federal Energy Administration, Washington, D.C.
U.S. Federal Power Commission, Washington, D.C.
U.S. Geological Survey, U.S. Department of the Interior, Washington, D.C.
U.S. House of Representatives, Committee on Science and Technology, Washington, D.C.
U.S. Nuclear Regulatory Commission, Washington, D.C.
U.S. Senate, Committee on Interior and Insular Affairs, Washington, D.C.
U.S. Water Resources Council, Washington, D.C.
World Bank, Washington, D.C.